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Higashino

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(54) **ENCODING DEVICE, ENCODING METHOD, RECORDING DEVICE, RECORDING METHOD, OPTICAL RECORDING MEDIUM, DECODING DEVICE AND DECODING METHOD**

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(51) **Int. Cl.**
G11B 20/14 (2006.01)

(52) **U.S. Cl.**
USPC **369/59.24**; 369/103; 341/59

(58) **Field of Classification Search**
USPC 341/52, 58, 59; 369/47.15, 59.24, 369/275.1, 275.4; 720/718
See application file for complete search history.

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(57) **ABSTRACT**

An encoding device for converting m-bit data words into n-bit (both n and m are integers and $2^n \geq 2^m \times 2$) code words includes a first encoding table in which 2^m code words selected from the 2^n n-bit code words correspond to 2^m m-bit data words, a second encoding table in which 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words, and an encoding unit which selects and outputs a code word, in which an absolute value of a code string DSV is smaller, from code words corresponding to the input m-bit data words in the first encoding table and code words corresponding to the input m-bit data words in the second encoding table.

17 Claims, 26 Drawing Sheets

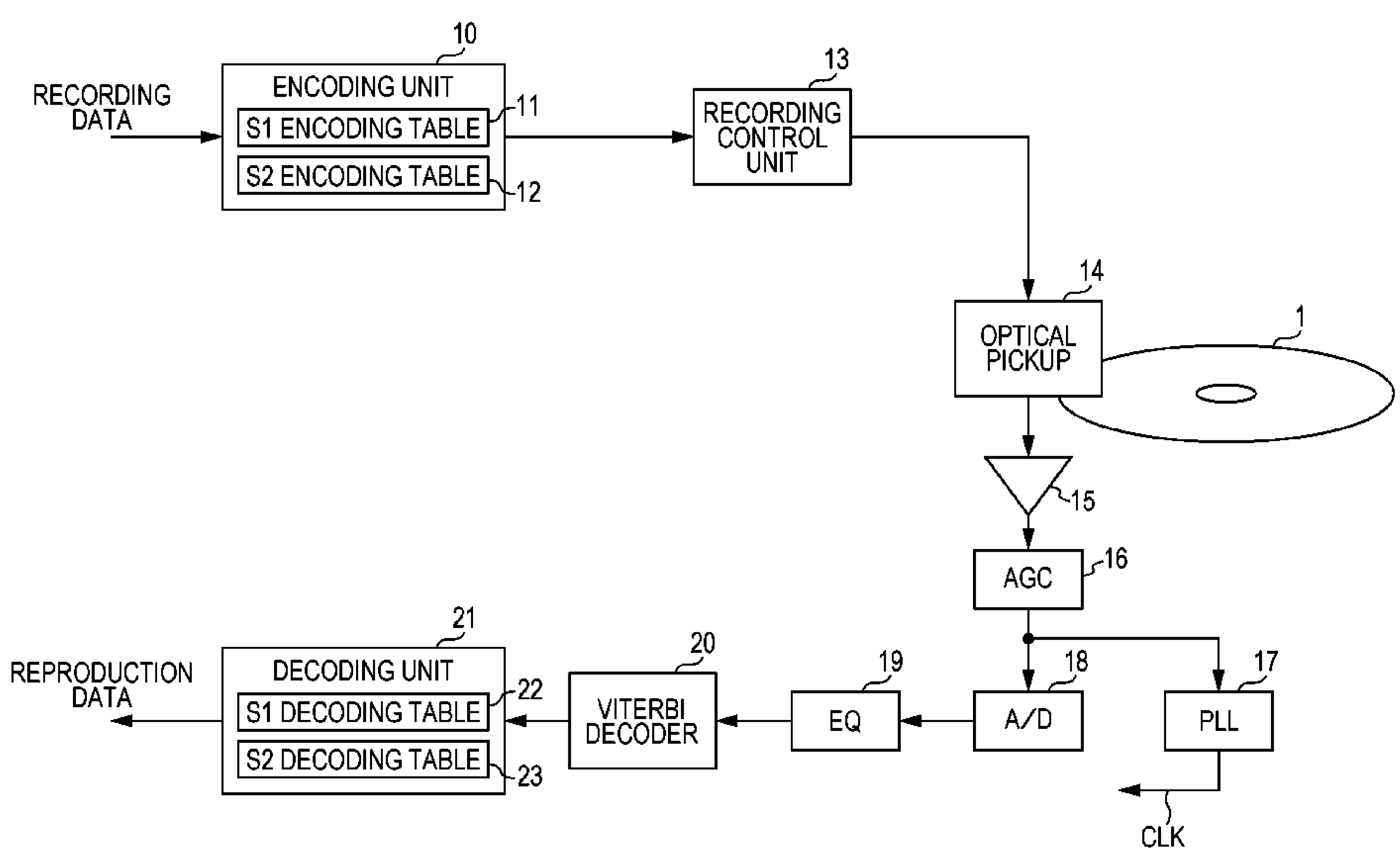


FIG. 1

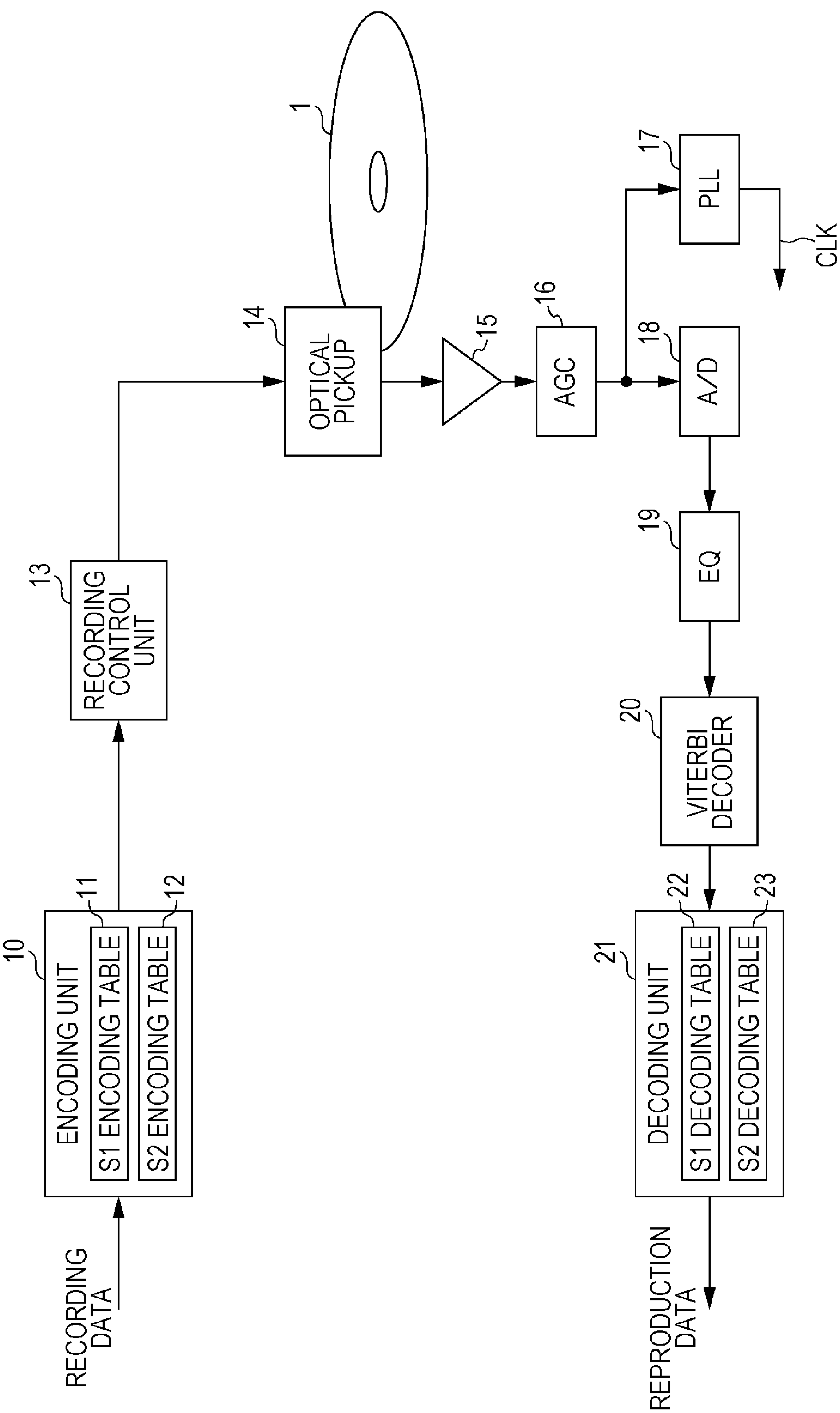
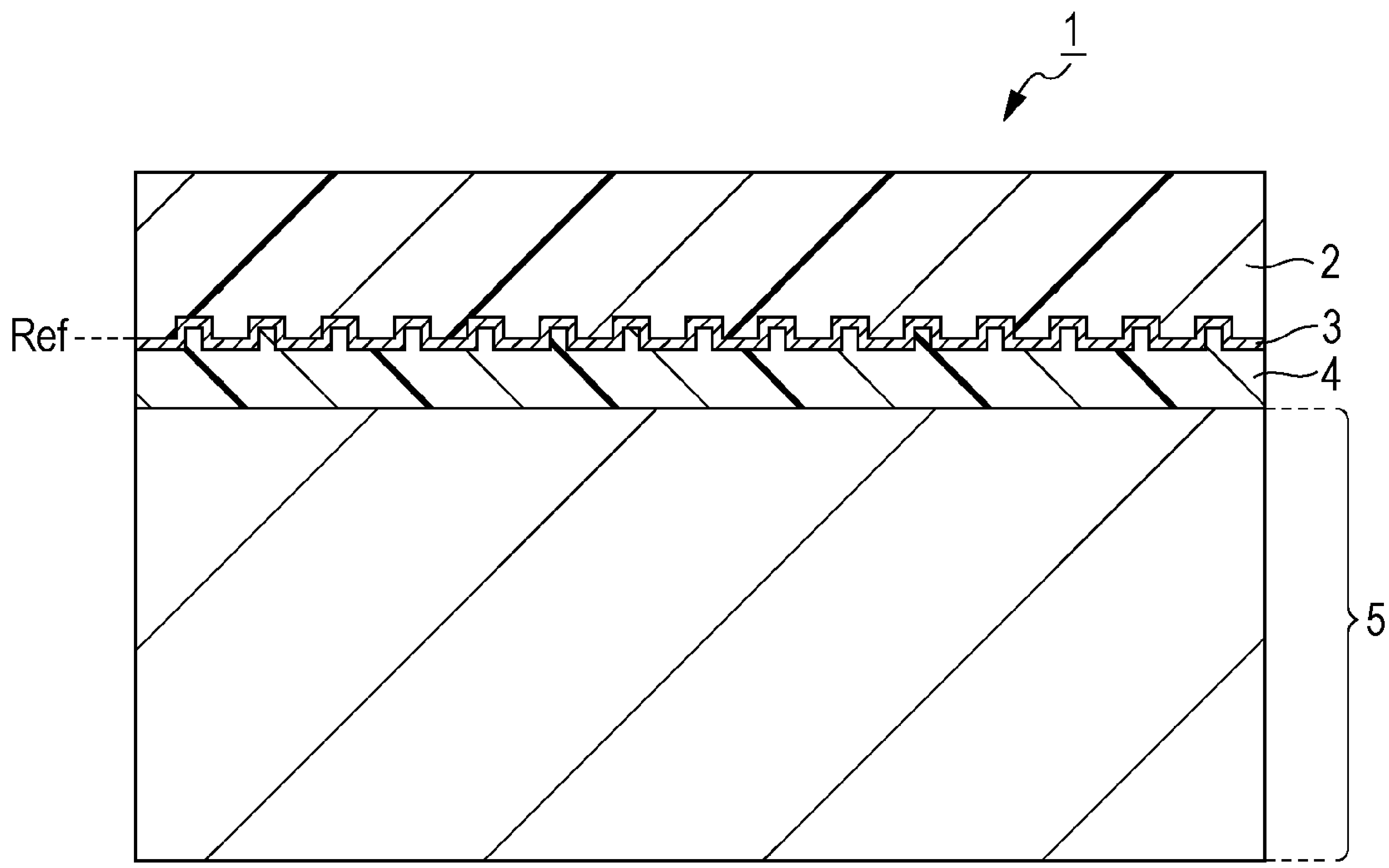

1
RECORDING DATA
10
ENCODING UNIT
11
S1 ENCODING TABLE
12
S2 ENCODING TABLE
13
RECORDING CONTROL UNIT
14
OPTICAL PICKUP
15
16
AGC
17
PLL
CLK
18
A/D
19
EQ
20
VITERBI DECODER
21
DECODING UNIT
22
S1 DECODING TABLE
23
S2 DECODING TABLE
REPRODUCTION DATA

FIG. 2



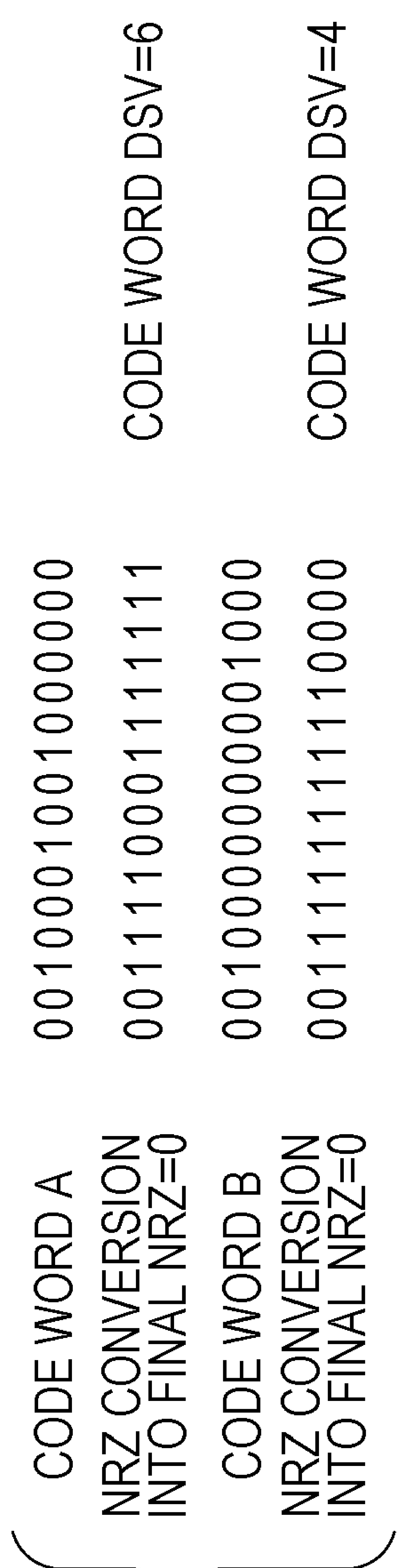

CODE WORD A
NRZ CONVERSION INTO FINAL NRZ=0
CODE WORD B
NRZ CONVERSION INTO FINAL NRZ=0
0010001001001000000
0011110001110000000
0010000000001000
0011111111110000
CODE WORD DSV=6
CODE WORD DSV=4

FIG. 3A

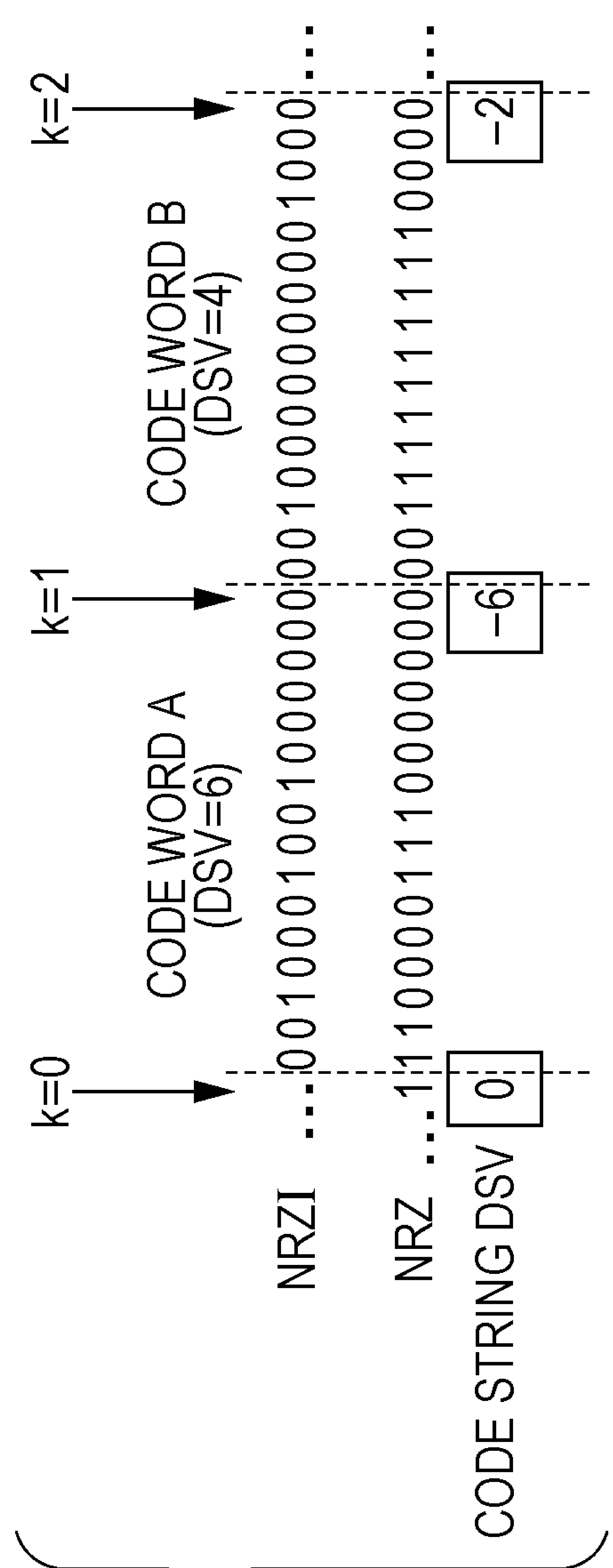

k=0
k=1
k=2
CODE WORD A (DSV=6)
CODE WORD B (DSV=4)
NRZI
NRZ
CODE STRING DSV
0
−6
−2

FIG. 3B

FIG. 4

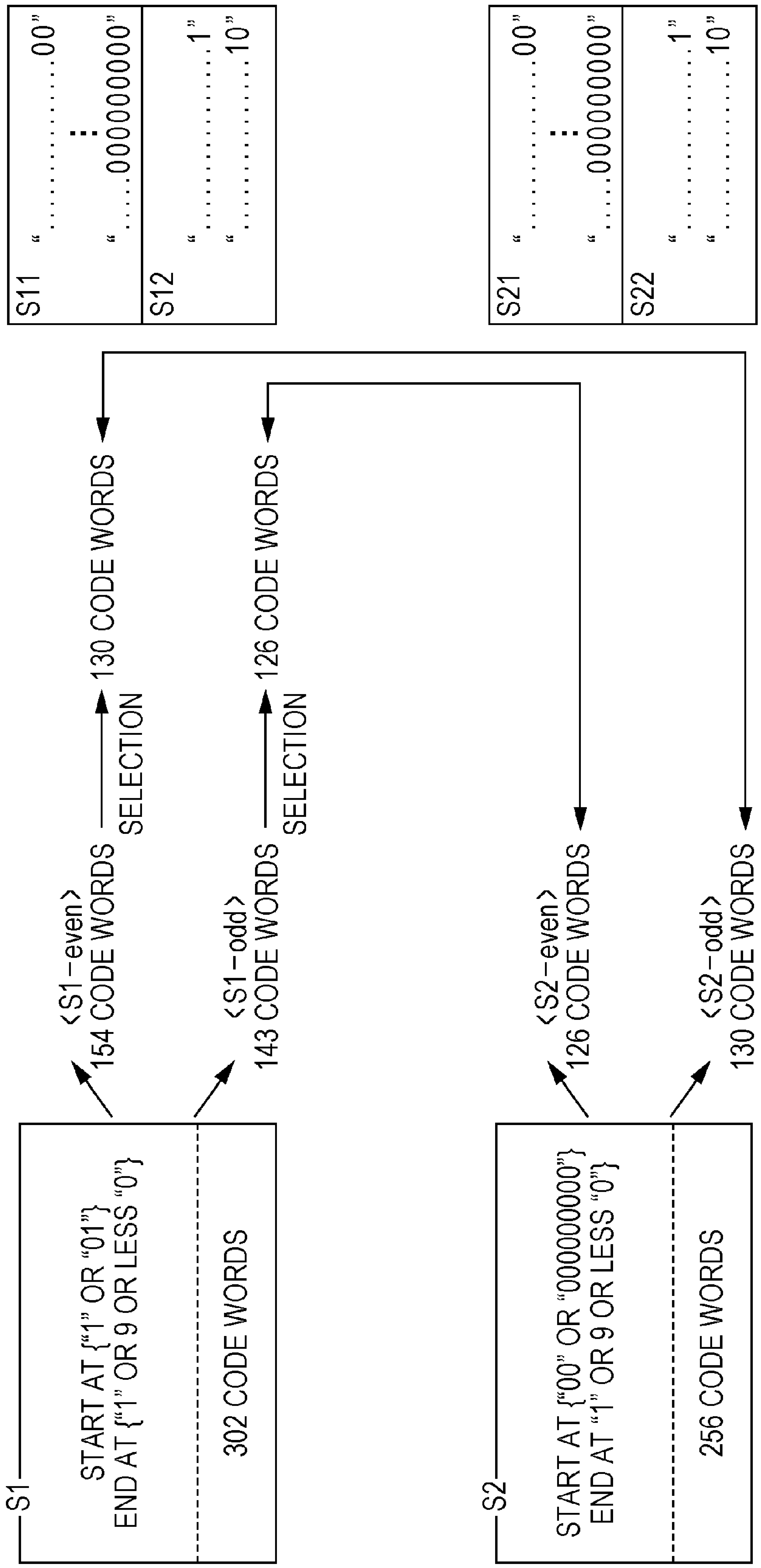

S1
START AT {"1" OR "01"}
END AT {"1" OR 9 OR LESS "0"}
302 CODE WORDS
⟨S1−even⟩
154 CODE WORDS
⟨S1−odd⟩
143 CODE WORDS
SELECTION
130 CODE WORDS
SELECTION
126 CODE WORDS
S2
START AT {"00" OR "000000000"}
END AT "1" OR 9 OR LESS "0"}
256 CODE WORDS
⟨S2−even⟩
126 CODE WORDS
⟨S2−odd⟩
130 CODE WORDS
S11
"..................00"
"......000000000"
S12
"..................1"
"..................10"
S21
"..................00"
"......000000000"
S22
"..................1"
"..................10"

FIG. 5

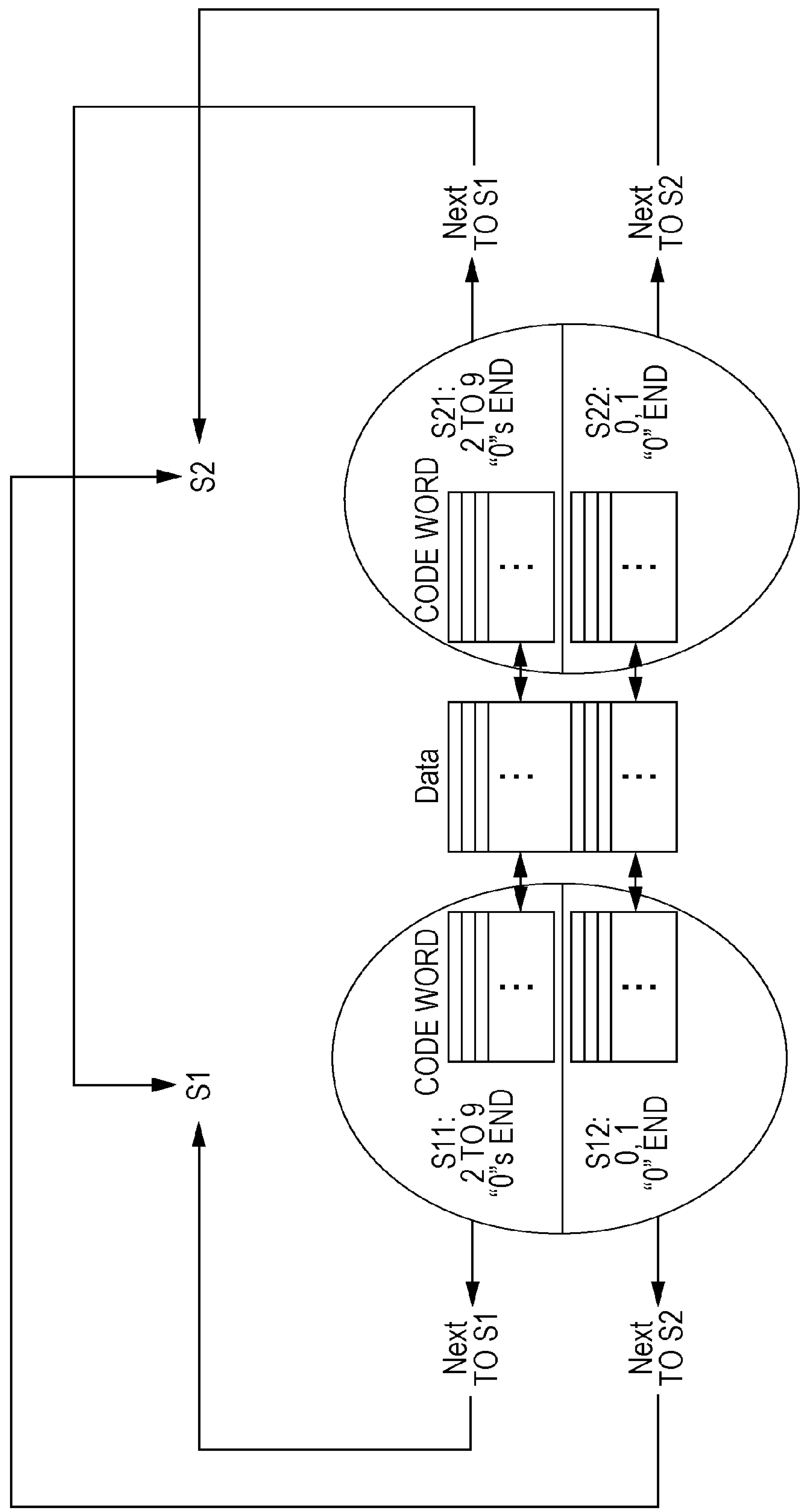

S1
S2
S11:
2 TO 9
"0"s END
S12:
0, 1
"0" END
CODE WORD
Data
S21:
2 TO 9
"0"s END
S22:
0, 1
"0" END
CODE WORD
Next
TO S1
Next
TO S2
Next
TO S1
Next
TO S2

FIG. 6

<S1>

	Data	Code	State	DSV	O/E
0	0x0	0100100100100000	1	−4	0
1	0x1	1001000010010000	1	−4	0
2	0x2	0100100010010000	1	−4	0
3	0x3	1001000001001000	1	−4	0
4	0x4	0100100001001000	1	−4	0
5	0x5	1001000000100100	1	−4	0
6	0x6	0100100000100100	1	−4	0
7	0x7	1001000000010010	2	−4	0
8	0x8	0100100000010010	2	−4	0
9	0x9	1001000000001001	2	−4	0
10	0xA	0100100000001001	2	−4	0
11	0xB	1000000100000000	1	−2	0
12	0xC	0100000010000000	1	−2	0
13	0xD	1001001000100000	1	−2	0
14	0xE	1000100100100000	1	−2	0
15	0xF	1001000100010000	1	−2	0
16	0x10	0100100100010000	1	−2	0
17	0x11	1000100010010000	1	−2	0
18	0x12	0100010010010000	1	−2	0
19	0x13	1001000010001000	1	−2	0
20	0x14	0100100010001000	1	−2	0
21	0x15	1000100001001000	1	−2	0
22	0x16	0100010001001000	1	−2	0
23	0x17	1001000001000100	1	−2	0
24	0x18	0100100001000100	1	−2	0
25	0x19	1000100000100100	1	−2	0
26	0x1A	0100010000100100	1	−2	0
27	0x1B	1001000000100010	2	−2	0
28	0x1C	0100100000100010	2	−2	0
29	0x1D	1000100000010010	2	−2	0
30	0x1E	0100010000010010	2	−2	0
31	0x1F	1001000000010001	2	−2	0
32	0x20	0100100000010001	2	−2	0
33	0x21	1000100000001001	2	−2	0
34	0x22	0100010000001001	2	−2	0
35	0x23	1000000010000000	1	0	0
36	0x24	0100000001000000	1	0	0
37	0x25	1001001000010000	1	0	0
38	0x26	1000100100010000	1	0	0
39	0x27	1000010010010000	1	0	0
40	0x28	1001000100001000	1	0	0
41	0x29	0100100100001000	1	0	0
42	0x2A	1000100010001000	1	0	0
43	0x2B	0100010010001000	1	0	0
44	0x2C	1000010001001000	1	0	0
45	0x2D	0100001001001000	1	0	0
46	0x2E	1001000010000100	1	0	0
47	0x2F	0100100010000100	1	0	0
48	0x30	1000100001000100	1	0	0
49	0x31	0100010001000100	1	0	0
50	0x32	1000010000100100	1	0	0
51	0x33	0100001000100100	1	0	0
52	0x34	1001000001000010	2	0	0
53	0x35	0100100001000010	2	0	0
54	0x36	1000100000100010	2	0	0
55	0x37	0100010000100010	2	0	0
56	0x38	1000010000010010	2	0	0
57	0x39	0100001000010010	2	0	0
58	0x3A	1001000000100001	2	0	0
59	0x3B	0100100000100001	2	0	0
60	0x3C	1000100000010001	2	0	0
61	0x3D	0100010000010001	2	0	0
62	0x3E	1000010000001001	2	0	0
63	0x3F	0100001000001001	2	0	0

FIG. 7

	Data	Code	State	DSV	O/E
64	0x40	1000000001000000	1	2	0
65	0x41	0100000000100000	1	2	0
66	0x42	1001001000001000	1	2	0
67	0x43	1000100100001000	1	2	0
68	0x44	1000010010001000	1	2	0
69	0x45	1000001001001000	1	2	0
70	0x46	1001000100000100	1	2	0
71	0x47	0100100100000100	1	2	0
72	0x48	1000100010000100	1	2	0
73	0x49	0100010010000100	1	2	0
74	0x4A	1000010001000100	1	2	0
75	0x4B	0100001001000100	1	2	0
76	0x4C	1000001000100100	1	2	0
77	0x4D	0100000100100100	1	2	0
78	0x4E	1001000010000010	2	2	0
79	0x4F	0100100010000010	2	2	0
80	0x50	1000100001000010	2	2	0
81	0x51	0100010001000010	2	2	0
82	0x52	1000010000100010	2	2	0
83	0x53	0100001000100010	2	2	0
84	0x54	1000001000010010	2	2	0
85	0x55	0100000100010010	2	2	0
86	0x56	1001000001000001	2	2	0
87	0x57	0100100001000001	2	2	0
88	0x58	1000100000100001	2	2	0
89	0x59	0100010000100001	2	2	0
90	0x5A	1000010000010001	2	2	0
91	0x5B	0100001000010001	2	2	0
92	0x5C	1000001000001001	2	2	0
93	0x5D	0100000100001001	2	2	0
94	0x5E	1001001001001001	2	2	0
95	0x5F	1000000000100000	1	4	0
96	0x60	0100000000010000	1	4	0
97	0x61	1001001000000100	1	4	0
98	0x62	1000100100000100	1	4	0
99	0x63	1000010010000100	1	4	0
100	0x64	1000001001000100	1	4	0
101	0x65	1000000100100100	1	4	0
102	0x66	1001000100000010	2	4	0
103	0x67	0100100100000010	2	4	0
104	0x68	1000100010000010	2	4	0
105	0x69	0100010010000010	2	4	0
106	0x6A	1000010001000010	2	4	0
107	0x6B	0100001001000010	2	4	0
108	0x6C	1000001000100010	2	4	0
109	0x6D	0100000100100010	2	4	0
110	0x6E	1000000100010010	2	4	0
111	0x6F	0100000010010010	2	4	0
112	0x70	1001000010000001	2	4	0
113	0x71	0100100010000001	2	4	0
114	0x72	1000100001000001	2	4	0
115	0x73	0100010001000001	2	4	0
116	0x74	1000010000100001	2	4	0
117	0x75	0100001000100001	2	4	0
118	0x76	1000001000010001	2	4	0
119	0x77	0100000100010001	2	4	0
120	0x78	1000000100001001	2	4	0
121	0x79	0100000010001001	2	4	0
122	0x7A	1000000000010000	1	6	0
123	0x7B	0100000000001000	1	6	0
124	0x7C	1001001000000010	2	6	0
125	0x7D	1000100100000010	2	6	0
126	0x7E	1000010010000010	2	6	0
127	0x7F	1000001001000010	2	6	0

FIG. 8

	Data	Code	State	DSV	O/E
128	0x80	1000000100100010	2	6	0
129	0x81	1000000010010010	2	6	0
130	0x82	0100010000000001	2	-6	1
131	0x83	1001000000000010	2	-6	1
132	0x84	0100100000000010	2	-6	1
133	0x85	1001000000000100	1	-4	1
134	0x86	0100100000000100	1	-4	1
135	0x87	1000010000000001	2	-4	1
136	0x88	0100001000000001	2	-4	1
137	0x89	1000100000000010	2	-4	1
138	0x8A	0100010000000010	2	-4	1
139	0x8B	1000100000000100	1	-2	1
140	0x8C	0100010000000100	1	-2	1
141	0x8D	1000001000000001	2	-2	1
142	0x8E	0100000100000001	2	-2	1
143	0x8F	1001001001000001	2	-2	1
144	0x90	1001000100100001	2	-2	1
145	0x91	0100100100100001	2	-2	1
146	0x92	1001000000001000	1	-2	1
147	0x93	0100100000001000	1	-2	1
148	0x94	1001000010010001	2	-2	1
149	0x95	0100100010010001	2	-2	1
150	0x96	1000010000000010	2	-2	1
151	0x97	0100001000000010	2	-2	1
152	0x98	1001000001001001	2	-2	1
153	0x99	0100100001001001	2	-2	1
154	0x9A	1001001001000010	2	0	1
155	0x9B	1001000000010000	1	0	1
156	0x9C	1001000100100010	2	0	1
157	0x9D	0100100100100010	2	0	1
158	0x9E	1000010000000100	1	0	1
159	0x9F	0100001000000100	1	0	1
160	0xA0	0100100000010000	1	0	1
161	0xA1	1001000010010010	2	0	1
162	0xA2	0100100010010010	2	0	1
163	0xA3	1000000100000001	2	0	1
164	0xA4	0100000010000001	2	0	1
165	0xA5	1001001000100001	2	0	1
166	0xA6	1000100100100001	2	0	1
167	0xA7	1000100000001000	1	0	1
168	0xA8	0100010000001000	1	0	1
169	0xA9	1001000100010001	2	0	1
170	0xAA	0100100100010001	2	0	1
171	0xAB	1000100010010001	2	0	1
172	0xAC	0100010010010001	2	0	1
173	0xAD	1000001000000010	2	0	1
174	0xAE	0100000100000010	2	0	1
175	0xAF	1001000010001001	2	0	1
176	0xB0	0100100010001001	2	0	1
177	0xB1	1000100001001001	2	0	1
178	0xB2	0100010001001001	2	0	1
179	0xB3	0100100000100000	1	2	1
180	0xB4	1001001000100010	2	2	1
181	0xB5	1000100100100010	2	2	1
182	0xB6	1000001000000100	1	2	1
183	0xB7	1000100000010000	1	2	1
184	0xB8	1001000100010010	2	2	1
185	0xB9	0100100100010010	2	2	1
186	0xBA	0100000100000100	1	2	1
187	0xBB	1000100010010010	2	2	1
188	0xBC	0100010010010010	2	2	1
189	0xBD	0100010000010000	1	2	1
190	0xBE	1000000010000001	2	2	1
191	0xBF	0100000001000001	2	2	1

FIG. 9

	Data	Code	State	DSV	O/E
192	0xC0	1001001001000100	1	2	1
193	0xC1	1000010000001000	1	2	1
194	0xC2	1001000100100100	1	2	1
195	0xC3	1001001000010001	2	2	1
196	0xC4	0100100100100100	1	2	1
197	0xC5	1000100100010001	2	2	1
198	0xC6	1000010010010001	2	2	1
199	0xC7	1000000100000010	2	2	1
200	0xC8	0100001000001000	1	2	1
201	0xC9	1001000100001001	2	2	1
202	0xCA	0100100100001001	2	2	1
203	0xCB	1001000000100000	1	2	1
204	0xCC	1000100010001001	2	2	1
205	0xCD	0100010010001001	2	2	1
206	0xCE	0100000010000010	2	2	1
207	0xCF	1000010001001001	2	2	1
208	0xD0	0100001001001001	2	2	1
209	0xD1	1000100000100000	1	4	1
210	0xD2	0100000001000010	2	4	1
211	0xD3	0100010000100000	1	4	1
212	0xD4	1001001001001000	1	4	1
213	0xD5	1001001000010010	2	4	1
214	0xD6	1000000100000100	1	4	1
215	0xD7	1000100100010010	2	4	1
216	0xD8	1000010010010010	2	4	1
217	0xD9	1000010000010000	1	4	1
218	0xDA	0100000010000100	1	4	1
219	0xDB	0100001000010000	1	4	1
220	0xDC	1001000001000000	1	4	1
221	0xDD	1000000001000001	2	4	1
222	0xDE	0100100001000000	1	4	1
223	0xDF	0100000000100001	2	4	1
224	0xE0	1001001000100100	1	4	1
225	0xE1	1000100100100100	1	4	1
226	0xE2	1000001000001000	1	4	1
227	0xE3	1001001000001001	2	4	1
228	0xE4	1000100100001001	2	4	1
229	0xE5	1000010010001001	2	4	1
230	0xE6	1000000010000010	2	4	1
231	0xE7	1000001001001001	2	4	1
232	0xE8	0100000100001000	1	4	1
233	0xE9	1000010000100000	1	6	1
234	0xEA	1000000001000010	2	6	1
235	0xEB	0100000010001000	1	6	1
236	0xEC	0100001001000000	1	6	1
237	0xED	0100000000100010	2	6	1
238	0xEE	0100100010000000	1	6	1
239	0xEF	1000000010000100	1	6	1
240	0xF0	1000001000010000	1	6	1
241	0xF1	0100000100010000	1	6	1
242	0xF2	0100000001000100	1	6	1
243	0xF3	1000100001000000	1	6	1
244	0xF4	1000000000100001	2	6	1
245	0xF5	0100010001000000	1	6	1
246	0xF6	1001000010000000	1	6	1
247	0xF7	0100000000010001	2	6	1
248	0xF8	1000000100001000	1	6	1
249	0xF9	1000000010001000	1	8	1
250	0xFA	1000001001000000	1	8	1
251	0xFB	1000100010000000	1	8	1
252	0xFC	1000000000100010	2	8	1
253	0xFD	0100000001001000	1	8	1
254	0xFE	0100001001000000	1	8	1
255	0xFF	0100010010000000	1	8	1

FIG. 10

<S2>

	Data	Code	State	DSV	mod2
0	0x0	0010001001000000	1	6	1
1	0x1	0010000001001000	1	6	1
2	0x2	0010000000010010	2	6	1
3	0x3	0010010010000000	1	6	1
4	0x4	0010000010010000	1	6	1
5	0x5	0010000000100100	1	6	1
6	0x6	0010000000001001	2	6	1
7	0x7	0010000100100000	1	6	1
8	0x8	0010000010001000	1	4	1
9	0x9	0010000000100010	2	4	1
10	0xA	0001001001000000	1	4	1
11	0xB	0000001000000000	1	4	1
12	0xC	0001000001001000	1	4	1
13	0xD	0001000000010010	2	4	1
14	0xE	0010000100010000	1	4	1
15	0xF	0001000010010000	1	4	1
16	0x10	0010000001000100	1	4	1
17	0x11	0010000000010001	2	4	1
18	0x12	0010010001000000	1	4	1
19	0x13	0001000000100100	1	4	1
20	0x14	0010001000100000	1	4	1
21	0x15	0001000000001001	2	4	1
22	0x16	0001000100100000	1	4	1
23	0x17	0010000001000010	2	2	1
24	0x18	0001000010001000	1	2	1
25	0x19	0001000000100010	2	2	1
26	0x1A	0000100001001000	1	2	1
27	0x1B	0000100000010010	2	2	1
28	0x1C	0000000100000000	1	2	1
29	0x1D	0010001000010000	1	2	1
30	0x1E	0001000100010000	1	2	1
31	0x1F	0010010000100000	1	2	1
32	0x20	0010000010000100	1	2	1
33	0x21	0010000000100001	2	2	1
34	0x22	0001000001000100	1	2	1
35	0x23	0001000000010001	2	2	1
36	0x24	0000100010010000	1	2	1
37	0x25	0000100000100100	1	2	1
38	0x26	0000100000001001	2	2	1
39	0x27	0001001000100000	1	2	1
40	0x28	0000100100100000	1	2	1
41	0x29	0010000100001000	1	2	1
42	0x2A	0010000010000010	2	0	1
43	0x2B	0001000001000010	2	0	1
44	0x2C	0000100010001000	1	0	1
45	0x2D	0000100000100010	2	0	1
46	0x2E	0000010001001000	1	0	1
47	0x2F	0000010000010010	2	0	1
48	0x30	0000000010000000	1	0	1
49	0x31	0010010000010000	1	0	1
50	0x32	0001001000010000	1	0	1
51	0x33	0010010010010010	2	0	1
52	0x34	0000100100010000	1	0	1
53	0x35	0010000100000100	1	0	1
54	0x36	0010000001000001	2	0	1
55	0x37	0001000010000100	1	0	1
56	0x38	0001000000100001	2	0	1
57	0x39	0000100001000100	1	0	1
58	0x3A	0000100000010001	2	0	1
59	0x3B	0000010010010000	1	0	1
60	0x3C	0000010000100100	1	0	1
61	0x3D	0000010000001001	2	0	1
62	0x3E	0010001000001000	1	0	1
63	0x3F	0010010010001001	2	0	1

FIG. 11

	Data	Code	State	DSV	mod2
64	0x40	0001000100001000	1	0	1
65	0x41	0010001001001001	2	0	1
66	0x42	0010000100000010	2	−2	1
67	0x43	0000100100001000	1	−2	1
68	0x44	0001000010000010	2	−2	1
69	0x45	0000100001000010	2	−2	1
70	0x46	0000010010001000	1	−2	1
71	0x47	0000010000100010	2	−2	1
72	0x48	0000001000010010	2	−2	1
73	0x49	0000001001001000	1	−2	1
74	0x4A	0010001000000100	1	−2	1
75	0x4B	0001000100000100	1	−2	1
76	0x4C	0010000010000001	2	−2	1
77	0x4D	0001000001000001	2	−2	1
78	0x4E	0000100010000100	1	−2	1
79	0x4F	0000100000100001	2	−2	1
80	0x50	0000010000010001	2	−2	1
81	0x51	0000010001000100	1	−2	1
82	0x52	0010010010010001	2	−2	1
83	0x53	0000001000100100	1	−2	1
84	0x54	0000001000001001	2	−2	1
85	0x55	0000000001000000	1	−2	1
86	0x56	0010010000001000	1	−2	1
87	0x57	0001001000001000	1	−2	1
88	0x58	0010010001001001	2	−2	1
89	0x59	0001001001001001	2	−2	1
90	0x5A	0001000100000010	2	−4	1
91	0x5B	0000100010000010	2	−4	1
92	0x5C	0000010001000010	2	−4	1
93	0x5D	0000001000100010	2	−4	1
94	0x5E	0000000100010010	2	−4	1
95	0x5F	0010010000000100	1	−4	1
96	0x60	0001001000000100	1	−4	1
97	0x61	0010000100000001	2	−4	1
98	0x62	0001000010000001	2	−4	1
99	0x63	0000100100000100	1	−4	1
100	0x64	0000100001000001	2	−4	1
101	0x65	0000010000100001	2	−4	1
102	0x66	0000010010000100	1	−4	1
103	0x67	0000001000010001	2	−4	1
104	0x68	0000001001000100	1	−4	1
105	0x69	0000000100001001	2	−4	1
106	0x6A	0000000100100100	1	−4	1
107	0x6B	0010001000000010	2	−4	1
108	0x6C	0000100100000010	2	−6	1
109	0x6D	0000010010000010	2	−6	1
110	0x6E	0000001001000010	2	−6	1
111	0x6F	0000000100100010	2	−6	1
112	0x70	0000000010010010	2	−6	1
113	0x71	0010001000000001	2	−6	1
114	0x72	0001000100000001	2	−6	1
115	0x73	0000100010000001	2	−6	1
116	0x74	0000010001000001	2	−6	1
117	0x75	0000001000100001	2	−6	1
118	0x76	0000000100010001	2	−6	1
119	0x77	0000000010001001	2	−6	1
120	0x78	0010010000000010	2	−6	1
121	0x79	0001001000000010	2	−6	1
122	0x7A	0010010000000001	2	−8	1
123	0x7B	0001001000000001	2	−8	1
124	0x7C	0000100100000001	2	−8	1
125	0x7D	0000010010000001	2	−8	1
126	0x7E	0000001001000001	2	−8	1
127	0x7F	0000000100100001	2	−8	1

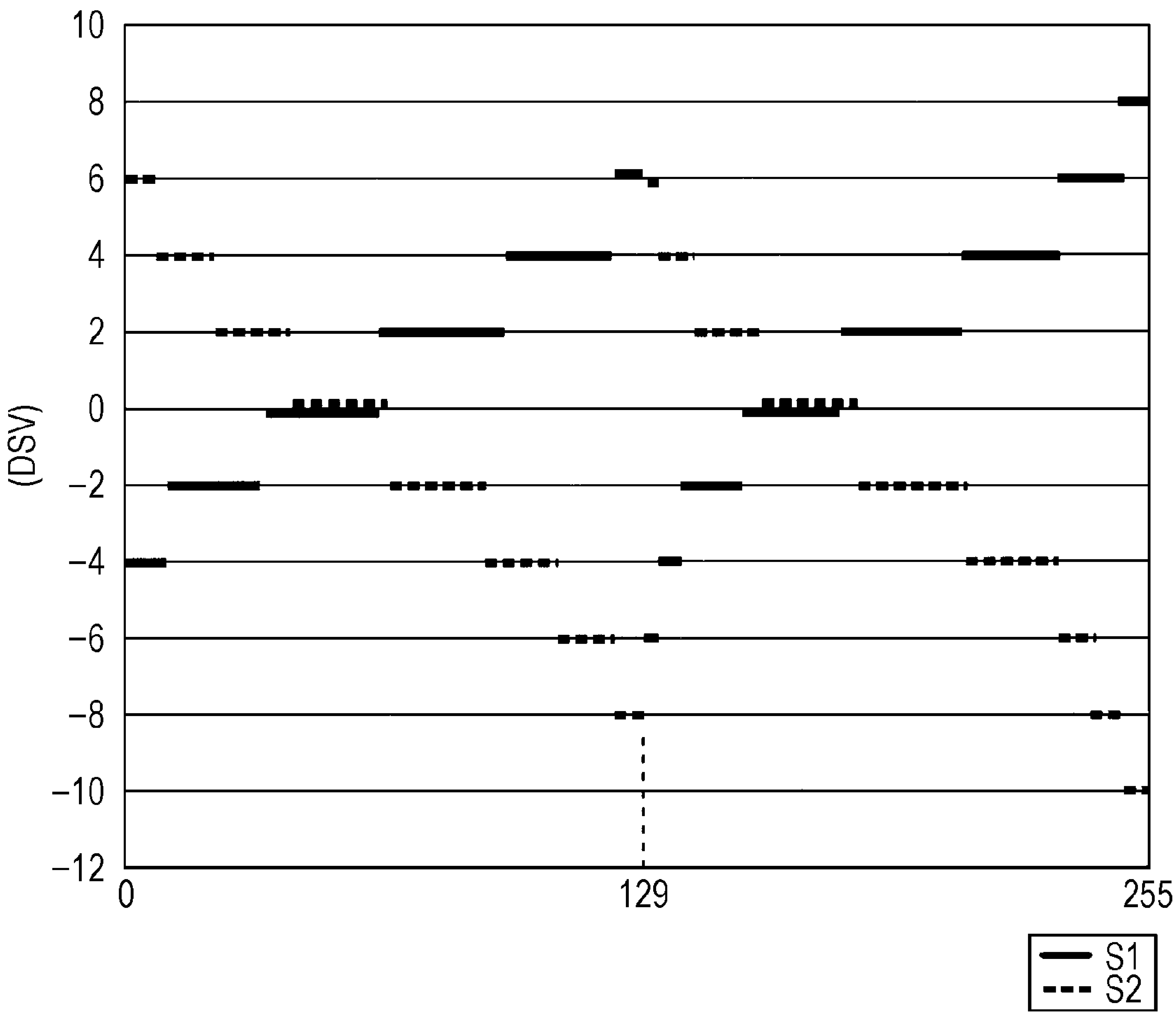
FIG. 12

	Data	Code	State	DSV	mod2
128	0x80	0000000010010001	2	−8	1
129	0x81	0000000001001001	2	−8	1
130	0x82	0010000000000100	1	6	0
131	0x83	0001000000000010	2	6	0
132	0x84	0000100000000001	2	6	0
133	0x85	0010000000001000	1	4	0
134	0x86	0001000000000100	1	4	0
135	0x87	0000100000000010	2	4	0
136	0x88	0000010000000001	2	4	0
137	0x89	0010010010000001	2	4	0
138	0x8A	0010001001000001	2	4	0
139	0x8B	0010000100100001	2	4	0
140	0x8C	0010000010010001	2	4	0
141	0x8D	0010000001001001	2	4	0
142	0x8E	0010000000010000	1	2	0
143	0x8F	0001000000001000	1	2	0
144	0x90	0000100000000100	1	2	0
145	0x91	0000010000000010	2	2	0
146	0x92	0010010010000010	2	2	0
147	0x93	0010001001000010	2	2	0
148	0x94	0010000100100010	2	2	0
149	0x95	0010000010010010	2	2	0
150	0x96	0000001000000001	2	2	0
151	0x97	0010010001000001	2	2	0
152	0x98	0001001001000001	2	2	0
153	0x99	0010001000100001	2	2	0
154	0x9A	0001000100100001	2	2	0
155	0x9B	0010000100010001	2	2	0
156	0x9C	0001000010010001	2	2	0
157	0x9D	0010000010001001	2	2	0
158	0x9E	0001000001001001	2	2	0
159	0x9F	0010000000100000	1	0	0
160	0xA0	0001000000010000	1	0	0
161	0xA1	0000100000001000	1	0	0
162	0xA2	0000010000000100	1	0	0
163	0xA3	0010010010000100	1	0	0
164	0xA4	0010001001000100	1	0	0
165	0xA5	0010000100100100	1	0	0
166	0xA6	0000001000000010	2	0	0
167	0xA7	0010010001000010	2	0	0
168	0xA8	0001001001000010	2	0	0
169	0xA9	0010001000100010	2	0	0
170	0xAA	0001000100100010	2	0	0
171	0xAB	0010000100010010	2	0	0
172	0xAC	0001000010010010	2	0	0
173	0xAD	0000000100000001	2	0	0
174	0xAE	0010010000100001	2	0	0
175	0xAF	0001001000100001	2	0	0
176	0xB0	0000100100100001	2	0	0
177	0xB1	0010001000010001	2	0	0
178	0xB2	0001000100010001	2	0	0
179	0xB3	0000100010010001	2	0	0
180	0xB4	0010000100001001	2	0	0
181	0xB5	0001000010001001	2	0	0
182	0xB6	0000100001001001	2	0	0
183	0xB7	0010000001000000	1	−2	0
184	0xB8	0001000000100000	1	−2	0
185	0xB9	0000100000010000	1	−2	0
186	0xBA	0000010000001000	1	−2	0
187	0xBB	0010010010001000	1	−2	0
188	0xBC	0010001001001000	1	−2	0
189	0xBD	0000001000000100	1	−2	0
190	0xBE	0010010001000100	1	−2	0
191	0xBF	0001001001000100	1	−2	0

FIG. 13

	Data	Code	State	DSV	mod2
192	0xC0	0010001000100100	1	−2	0
193	0xC1	0001000100100100	1	−2	0
194	0xC2	0000000100000010	2	−2	0
195	0xC3	0010010000100010	2	−2	0
196	0xC4	0001001000100010	2	−2	0
197	0xC5	0000100100100010	2	−2	0
198	0xC6	0010001000010010	2	−2	0
199	0xC7	0001000100010010	2	−2	0
200	0xC8	0000100010010010	2	−2	0
201	0xC9	0000000010000001	2	−2	0
202	0xCA	0010010000010001	2	−2	0
203	0xCB	0001001000010001	2	−2	0
204	0xCC	0000100100010001	2	−2	0
205	0xCD	0000010010010001	2	−2	0
206	0xCE	0010001000001001	2	−2	0
207	0xCF	0001000100001001	2	−2	0
208	0xD0	0000100010001001	2	−2	0
209	0xD1	0000010001001001	2	−2	0
210	0xD2	0010000010000000	1	−4	0
211	0xD3	0001000001000000	1	−4	0
212	0xD4	0000100000100000	1	−4	0
213	0xD5	0000010000010000	1	−4	0
214	0xD6	0010010010010000	1	−4	0
215	0xD7	0000001000001000	1	−4	0
216	0xD8	0010010001001000	1	−4	0
217	0xD9	0001001001001000	1	−4	0
218	0xDA	0000000100000100	1	−4	0
219	0xDB	0010010000100100	1	−4	0
220	0xDC	0001001000100100	1	−4	0
221	0xDD	0000100100100100	1	−4	0
222	0xDE	0000000010000010	2	−4	0
223	0xDF	0010010000010010	2	−4	0
224	0xE0	0001001000010010	2	−4	0
225	0xE1	0000100100010010	2	−4	0
226	0xE2	0000010010010010	2	−4	0
227	0xE3	0000000001000001	2	−4	0
228	0xE4	0010010000001001	2	−4	0
229	0xE5	0001001000001001	2	−4	0
230	0xE6	0000100100001001	2	−4	0
231	0xE7	0000010010001001	2	−4	0
232	0xE8	0000001001001001	2	−4	0
233	0xE9	0010000100000000	1	−6	0
234	0xEA	0001000010000000	1	−6	0
235	0xEB	0000100001000000	1	−6	0
236	0xEC	0000010000100000	1	−6	0
237	0xED	0000001000010000	1	−6	0
238	0xEE	0000000100001000	1	−6	0
239	0xEF	0000000010000100	1	−6	0
240	0xF0	0000000001000010	2	−6	0
241	0xF1	0010001000000000	1	−8	0
242	0xF2	0001000100000000	1	−8	0
243	0xF3	0000100010000000	1	−8	0
244	0xF4	0000010001000000	1	−8	0
245	0xF5	0000001000100000	1	−8	0
246	0xF6	0000000100010000	1	−8	0
247	0xF7	0000000010001000	1	−8	0
248	0xF8	0000000001000100	1	−8	0
249	0xF9	0001001000000000	1	−10	0
250	0xFA	0000100100000000	1	−10	0
251	0xFB	0000010010000000	1	−10	0
252	0xFC	0000001001000000	1	−10	0
253	0xFD	0000000100100000	1	−10	0
254	0xFE	0000000010010000	1	−10	0
255	0xFF	0000000001001000	1	−10	0

FIG. 14



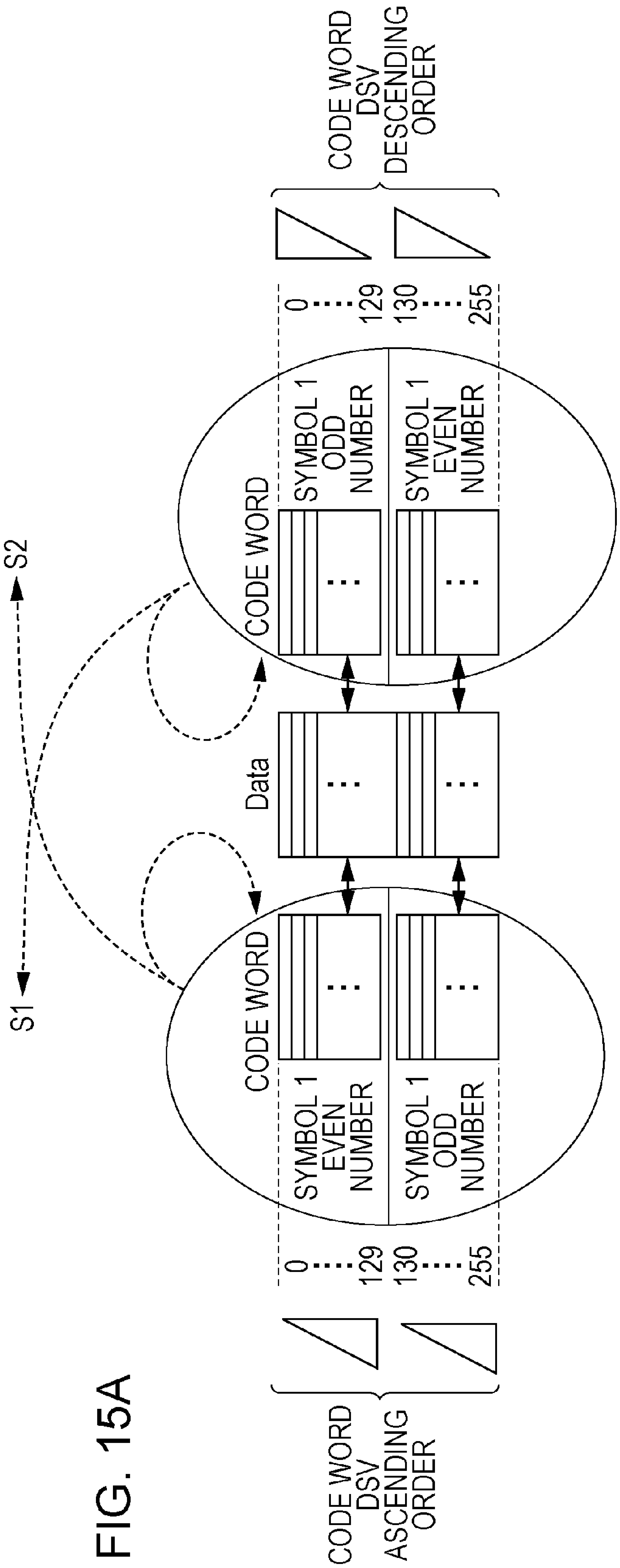


FIG. 15A

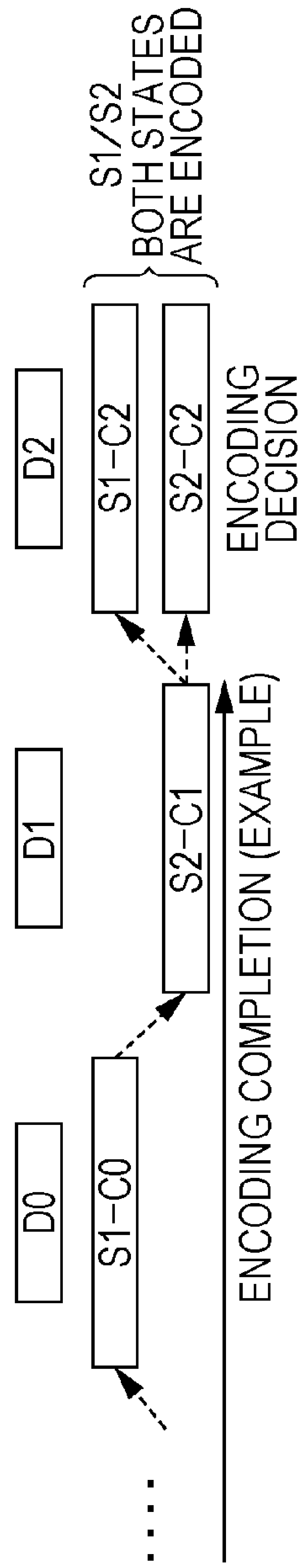


FIG. 15B

FIG. 16

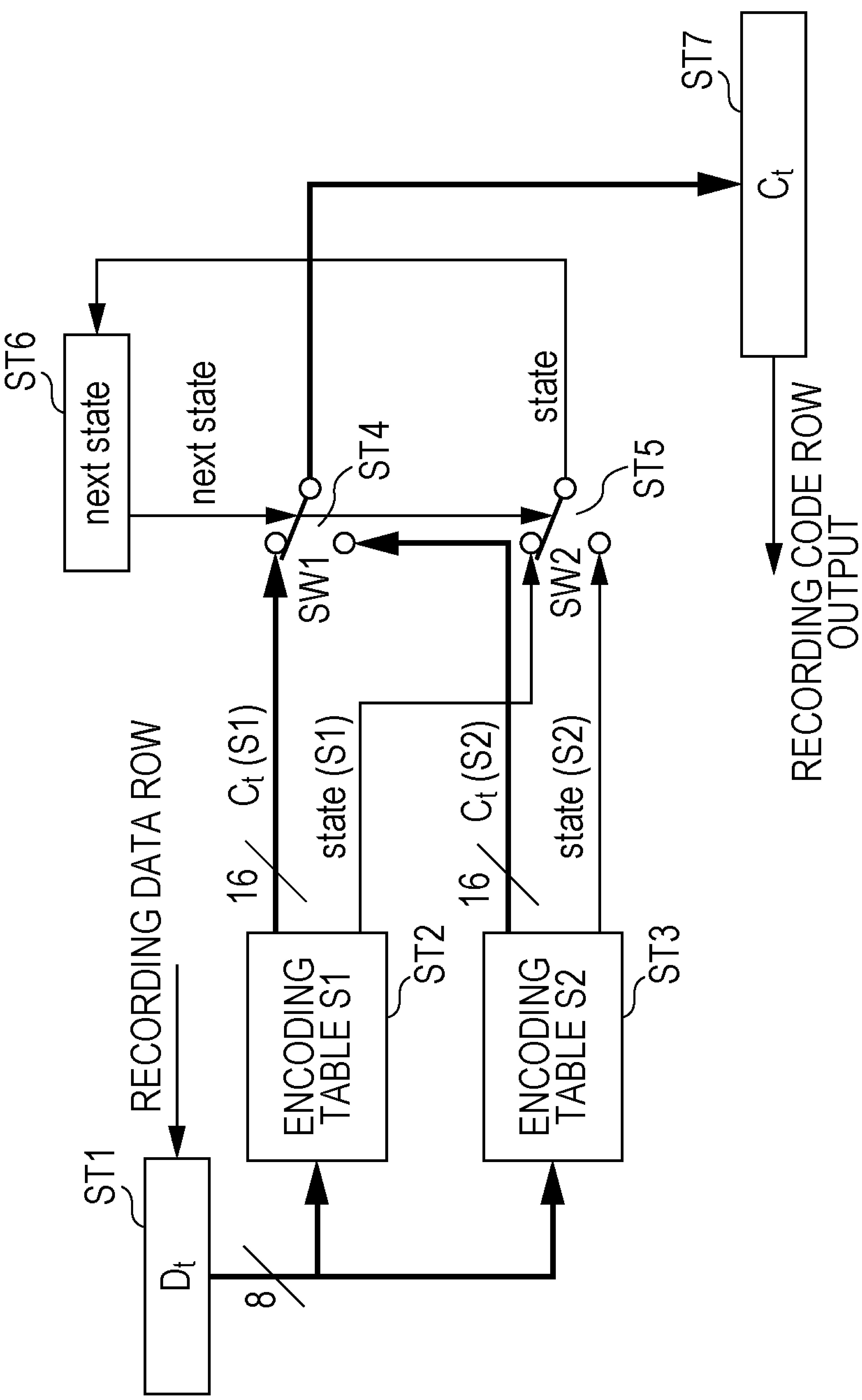

RECORDING DATA ROW
ST1
D_t
8
ENCODING TABLE S1
ST2
ENCODING TABLE S2
ST3
16
C_t (S1)
state (S1)
16
C_t (S2)
state (S2)
SW1
ST4
SW2
ST5
ST6
next state
next state
state
ST7
C_t
RECORDING CODE ROW OUTPUT

FIG. 17

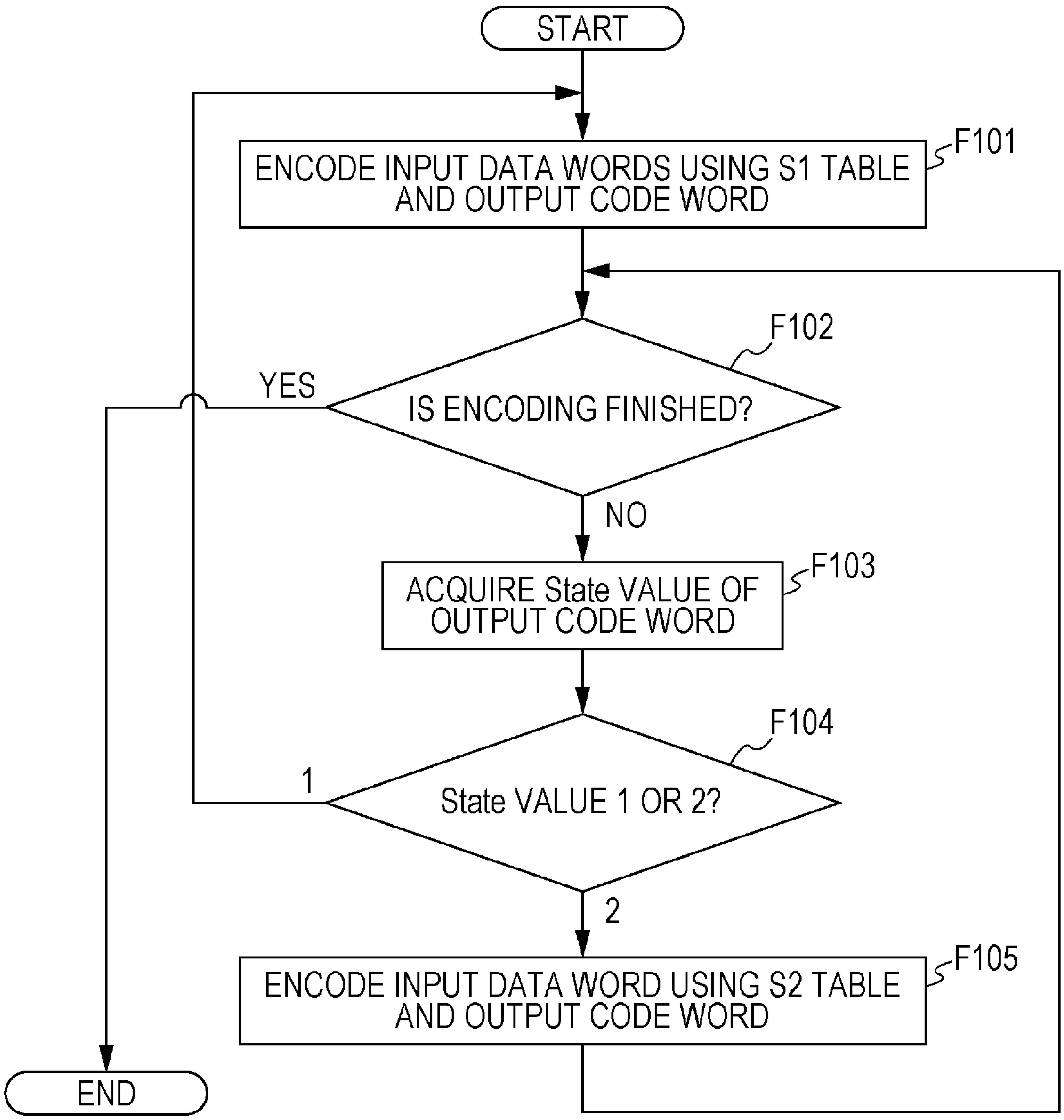

START
ENCODE INPUT DATA WORDS USING S1 TABLE AND OUTPUT CODE WORD
F101
IS ENCODING FINISHED?
F102
YES
NO
ACQUIRE State VALUE OF OUTPUT CODE WORD
F103
State VALUE 1 OR 2?
F104
1
2
ENCODE INPUT DATA WORD USING S2 TABLE AND OUTPUT CODE WORD
F105
END

FIG. 18

t	D_t	Next state	C_t	PRECEDING END NRZ	State	CODE WORD DSV	CODE STRING DSV
0	0x05	1	1001000000100100	0	1	−4	−4
1	0xfc	1	1000000000100010	0	2	8	4
2	0xf7	2	0000000010001000	1	1	−8	12
3	0x84	1	0100100000000010	1	2	−6	18
4	0xfa	2	0000100100000000	0	1	−10	8
5	0x07	1	1001000000010010	0	2	−4	4
...	...	2	...		...		

FIG. 19

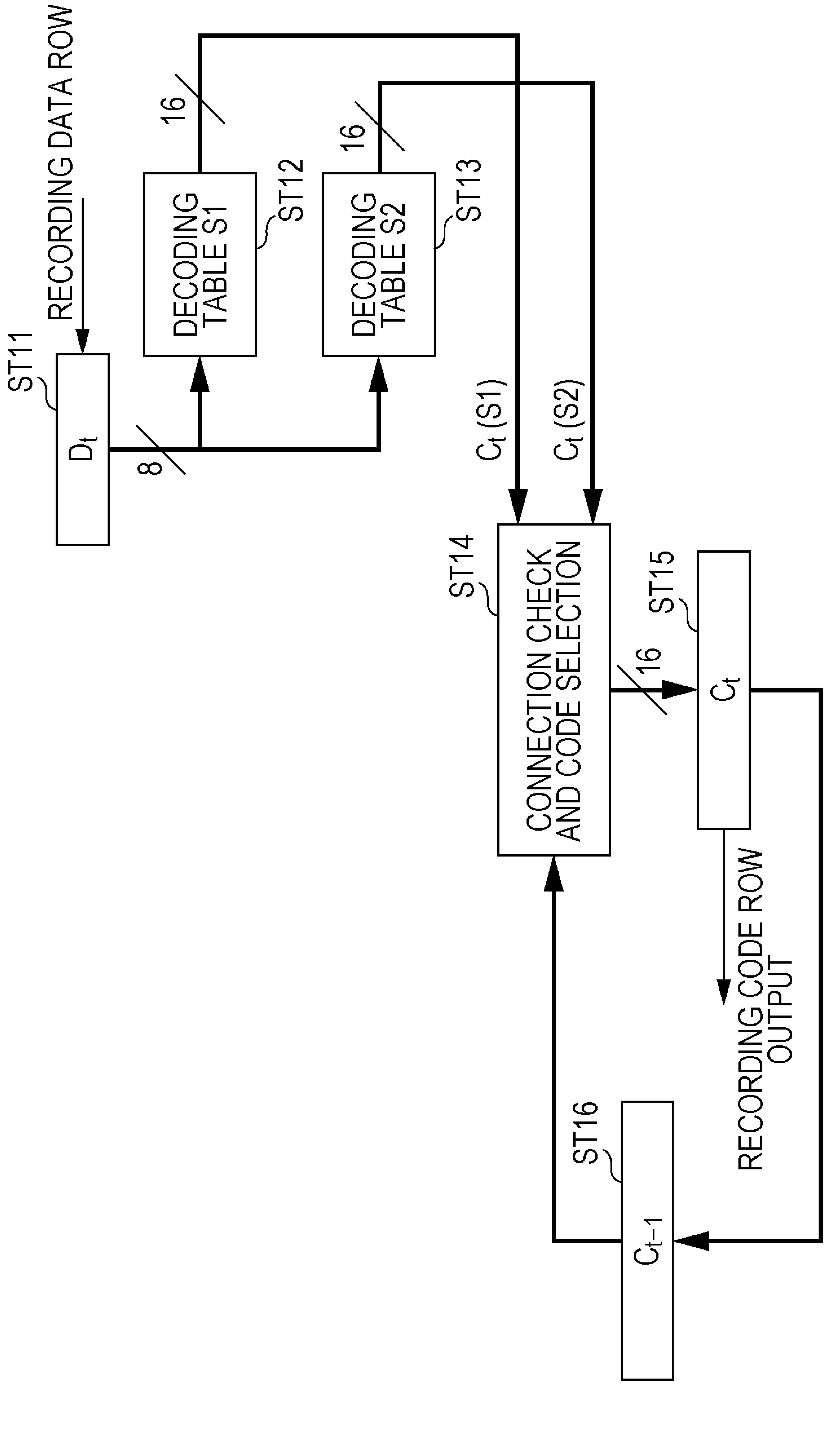

RECORDING DATA ROW
ST11
D_t
8
DECODING TABLE S1
ST12
16
DECODING TABLE S2
ST13
16
C_t (S1)
C_t (S2)
ST14
CONNECTION CHECK AND CODE SELECTION
16
ST15
C_t
RECORDING CODE ROW OUTPUT
ST16
C_{t-1}

FIG. 20

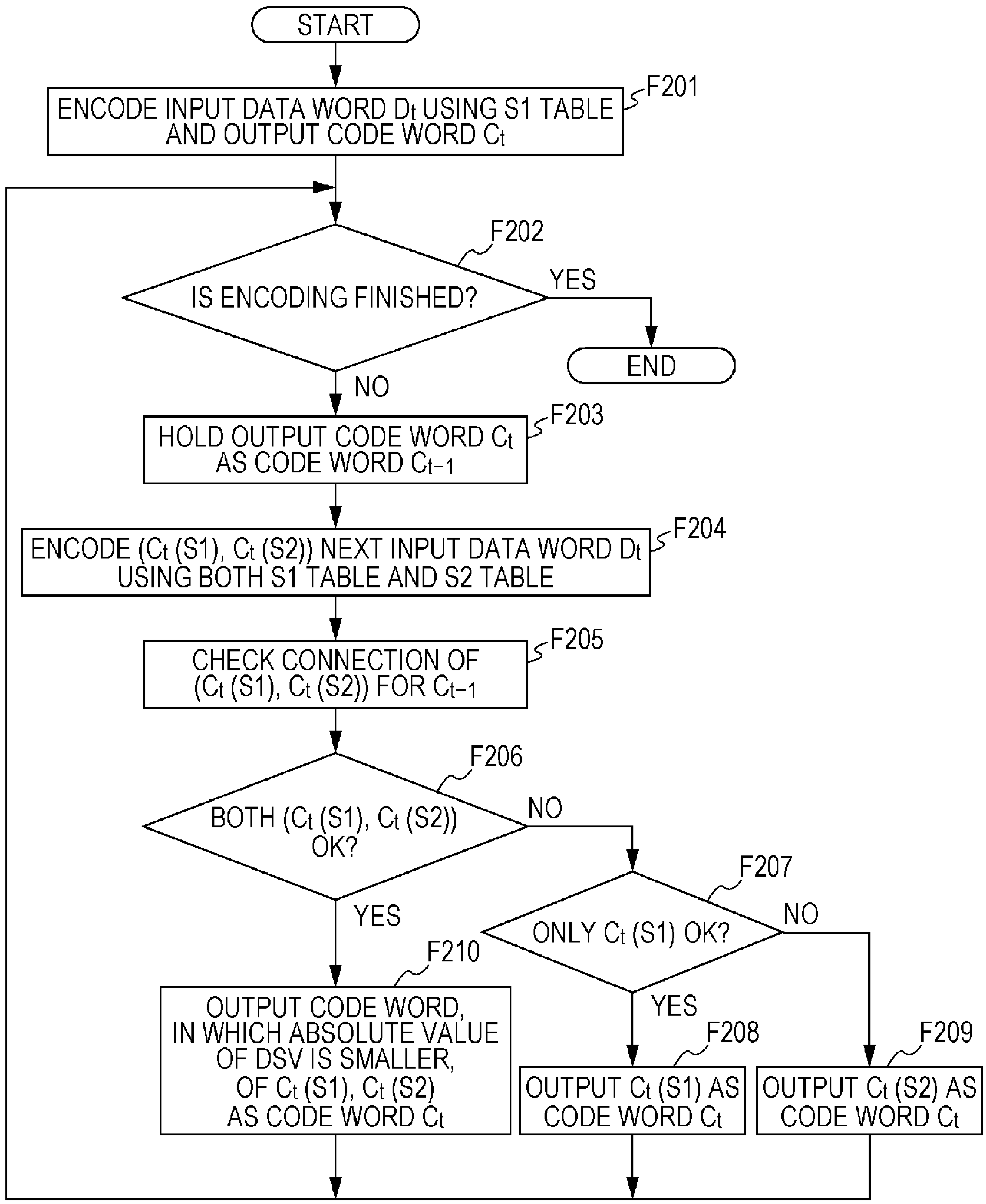

START
ENCODE INPUT DATA WORD Dt USING S1 TABLE AND OUTPUT CODE WORD Ct
F201
IS ENCODING FINISHED?
F202
YES
END
NO
HOLD OUTPUT CODE WORD Ct AS CODE WORD Ct-1
F203
ENCODE (Ct (S1), Ct (S2)) NEXT INPUT DATA WORD Dt USING BOTH S1 TABLE AND S2 TABLE
F204
CHECK CONNECTION OF (Ct (S1), Ct (S2)) FOR Ct-1
F205
BOTH (Ct (S1), Ct (S2)) OK?
F206
NO
ONLY Ct (S1) OK?
F207
NO
YES
OUTPUT CODE WORD, IN WHICH ABSOLUTE VALUE OF DSV IS SMALLER, OF Ct (S1), Ct (S2) AS CODE WORD Ct
F210
YES
OUTPUT Ct (S1) AS CODE WORD Ct
F208
OUTPUT Ct (S2) AS CODE WORD Ct
F209

FIG. 21

t	D_t	Next state	C_t	PRECEDING END NRZ	State	CODE WORD DSV	CODE STRING DSV	CONNECTION CONDITION
0	0x05	1	1001000000100100	0	1	−4	−4	–
1	0xfc	1	1000000000100010	0	2	8	4	CONDITION 3
2	0xf7	1	0100000000010001	1	2	6	−2	CONDITION 3
3	0x84	2	0000100000000001	0	2	6	4	CONDITION 2
4	0xfa	2	0000100100000000	0	1	−10	−6	CONDITION 2
5	0x07	2	0010000100100000	0	1	6	0	CONDITION 3
...	...	...	...	1	...			

FIG. 22

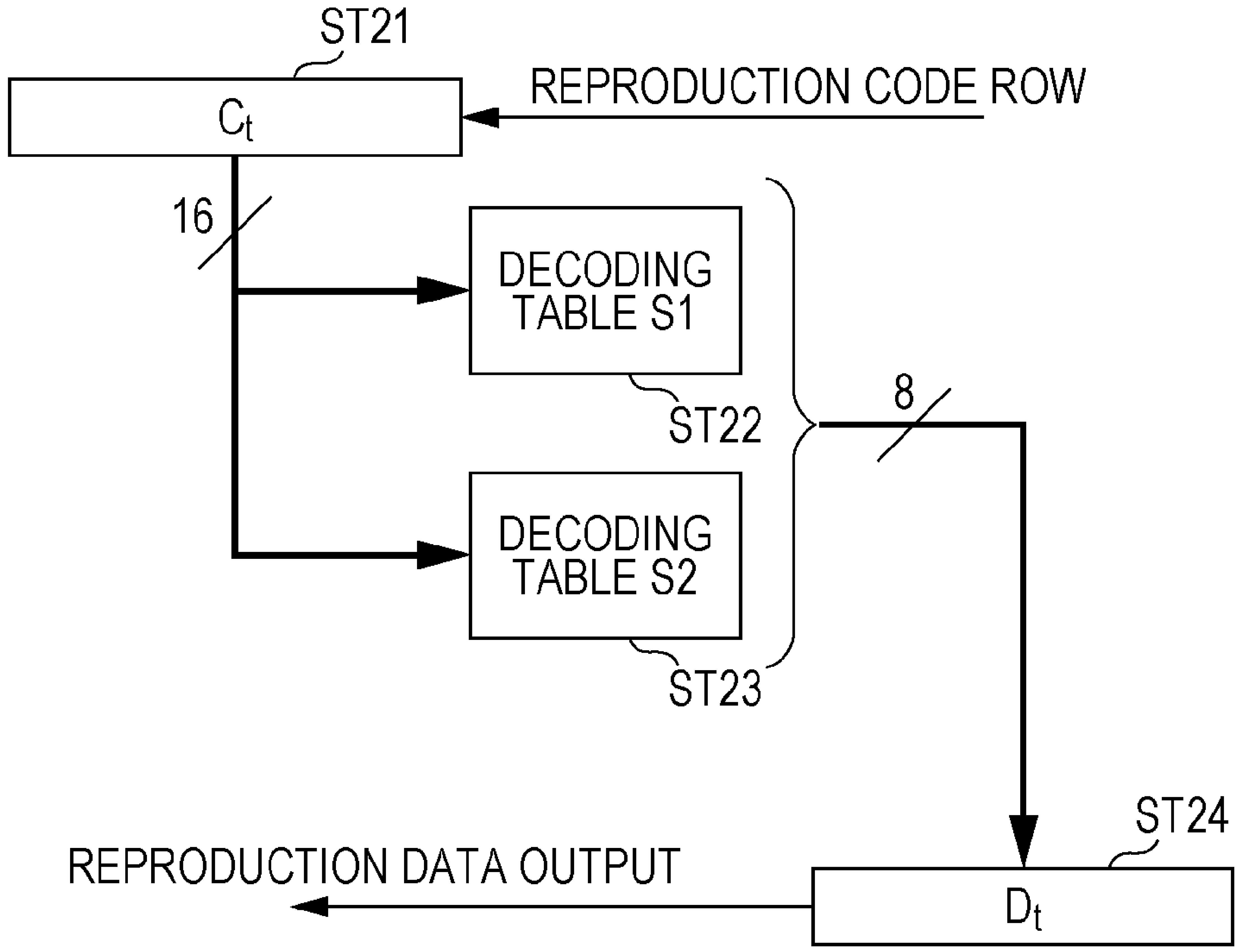

ST21
C_t
REPRODUCTION CODE ROW
16
DECODING TABLE S1
ST22
8
DECODING TABLE S2
ST23
ST24
REPRODUCTION DATA OUTPUT
D_t

FIG. 23

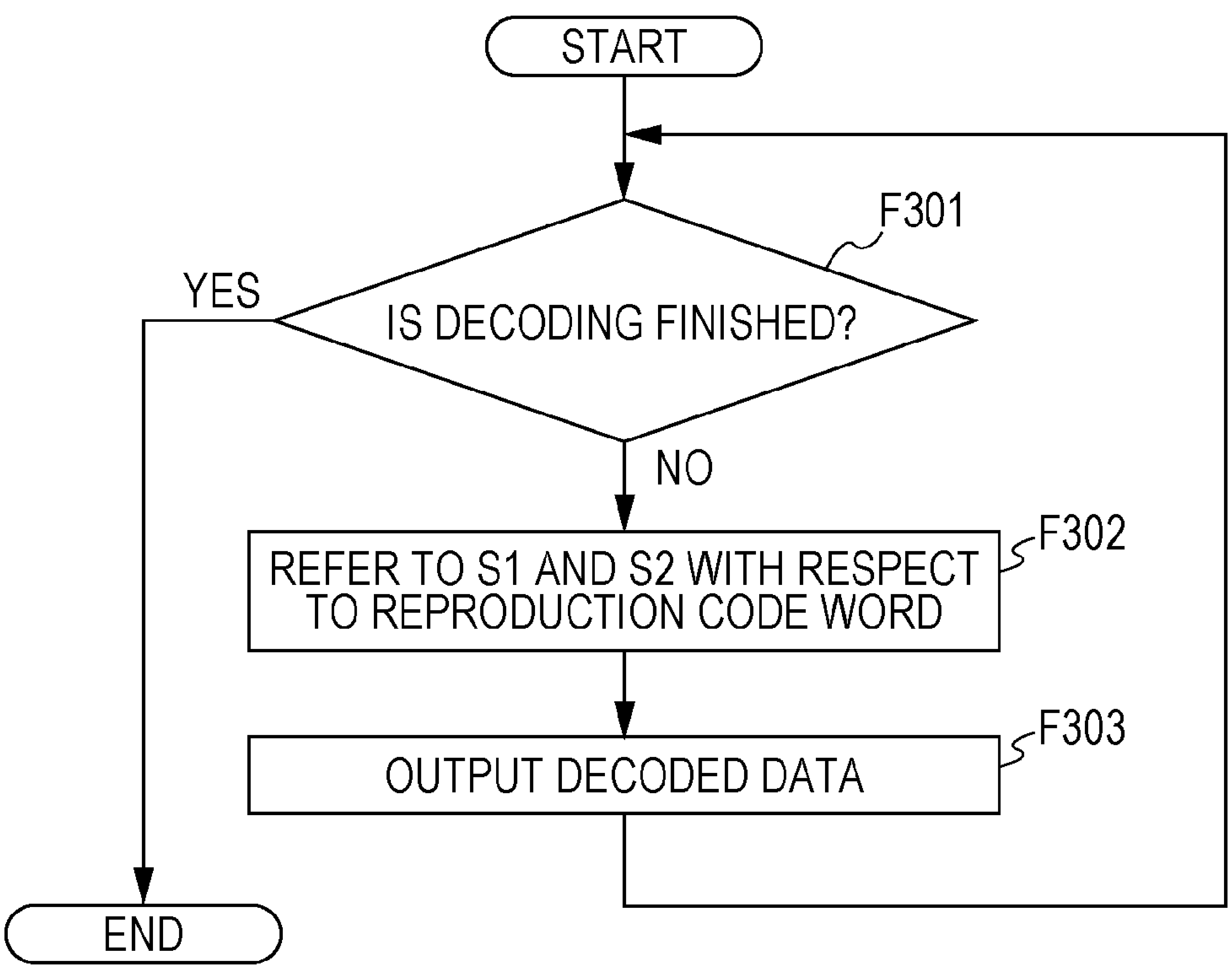

START
F301
YES
IS DECODING FINISHED?
NO
REFER TO S1 AND S2 WITH RESPECT TO REPRODUCTION CODE WORD
F302
OUTPUT DECODED DATA
F303
END

FIG. 24

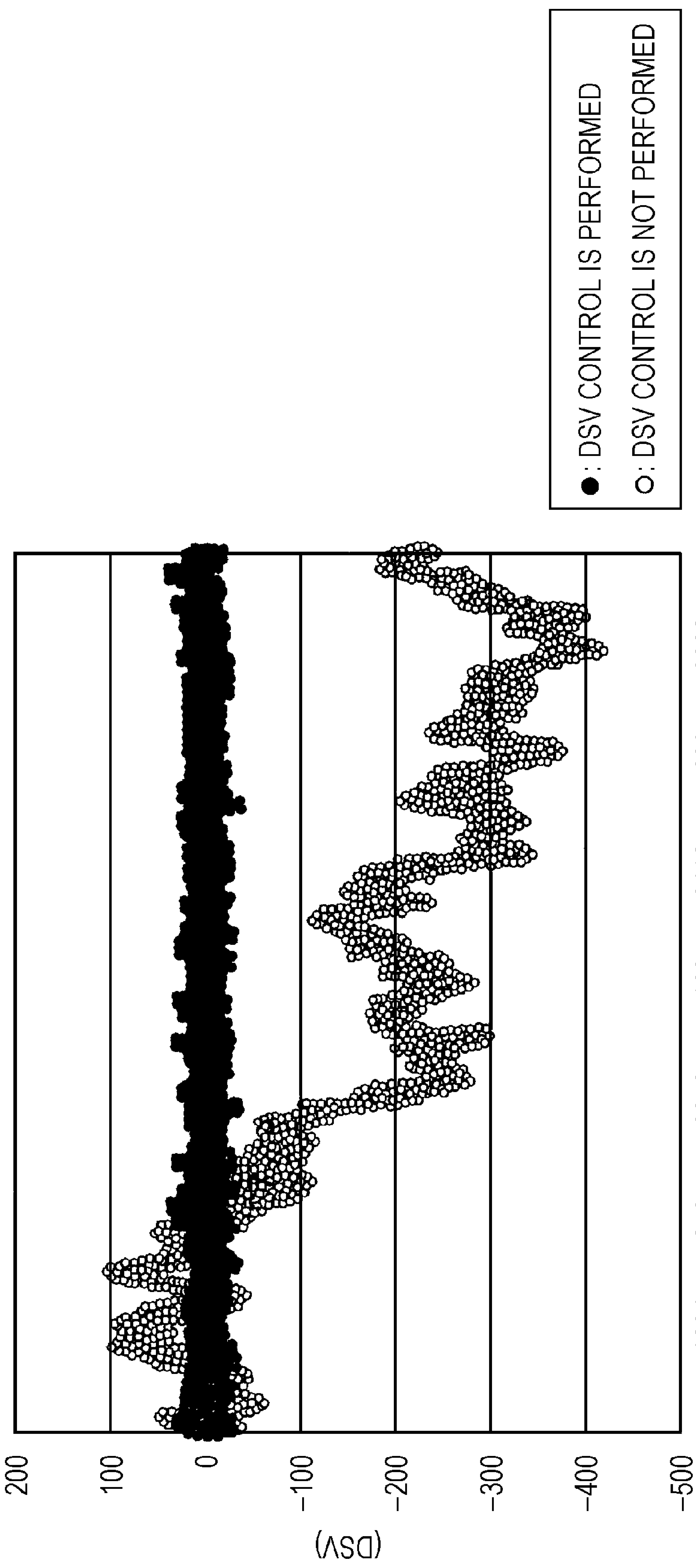
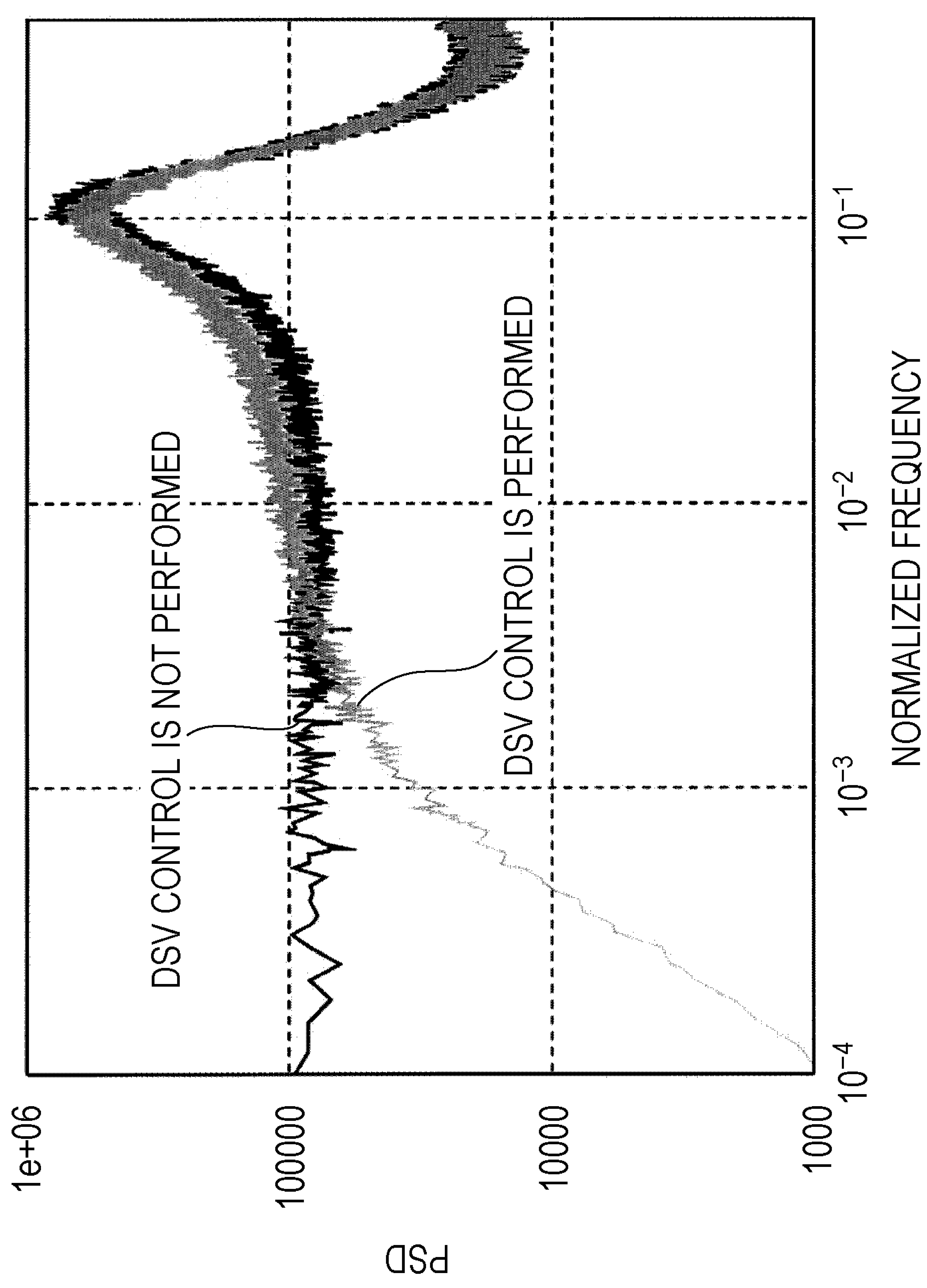
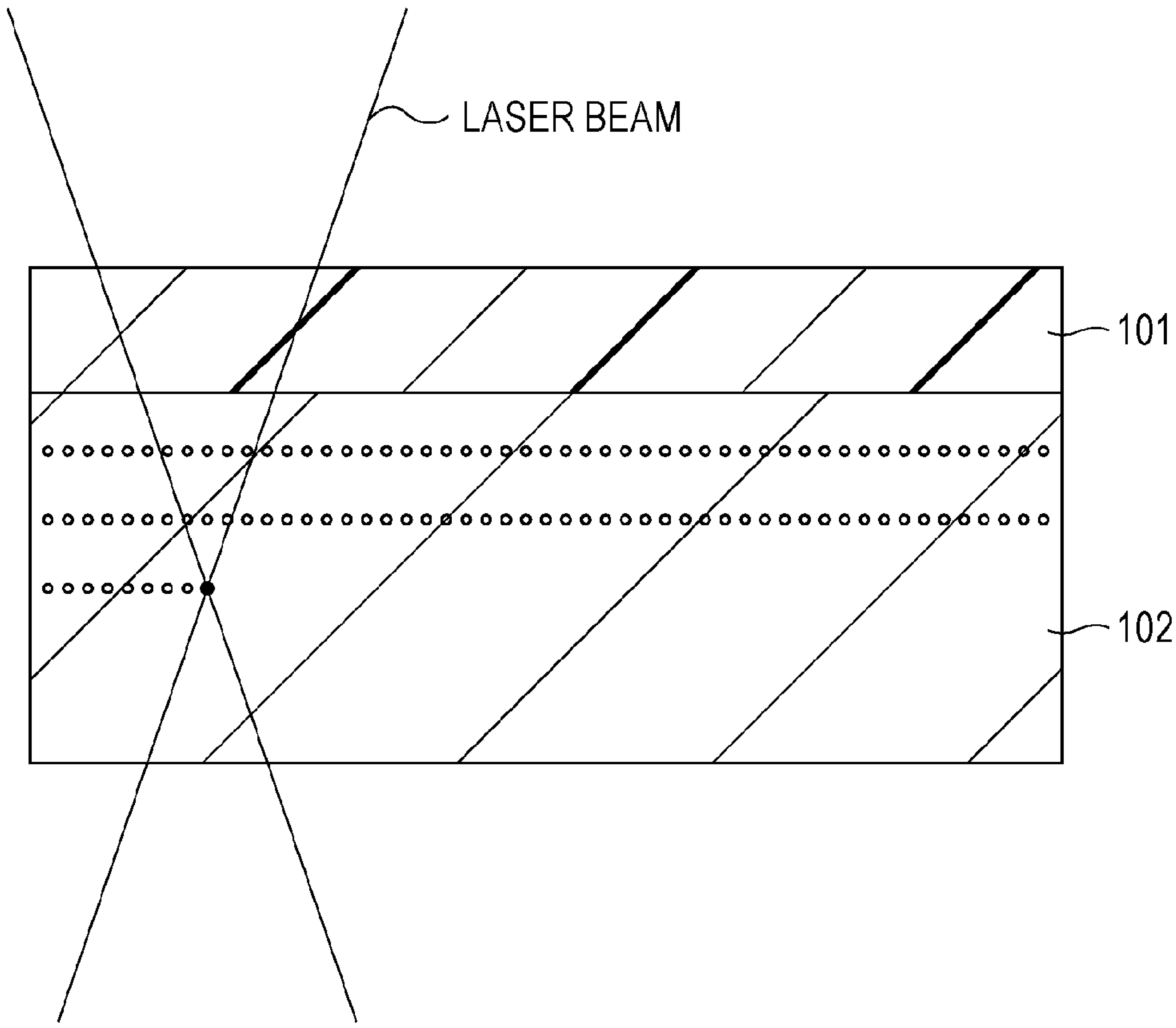

●: DSV CONTROL IS PERFORMED
○: DSV CONTROL IS NOT PERFORMED
(DSV)
200
100
0
−100
−200
−300
−400
−500
1284
2567
3850
5133
6416
7699
8982

FIG. 25



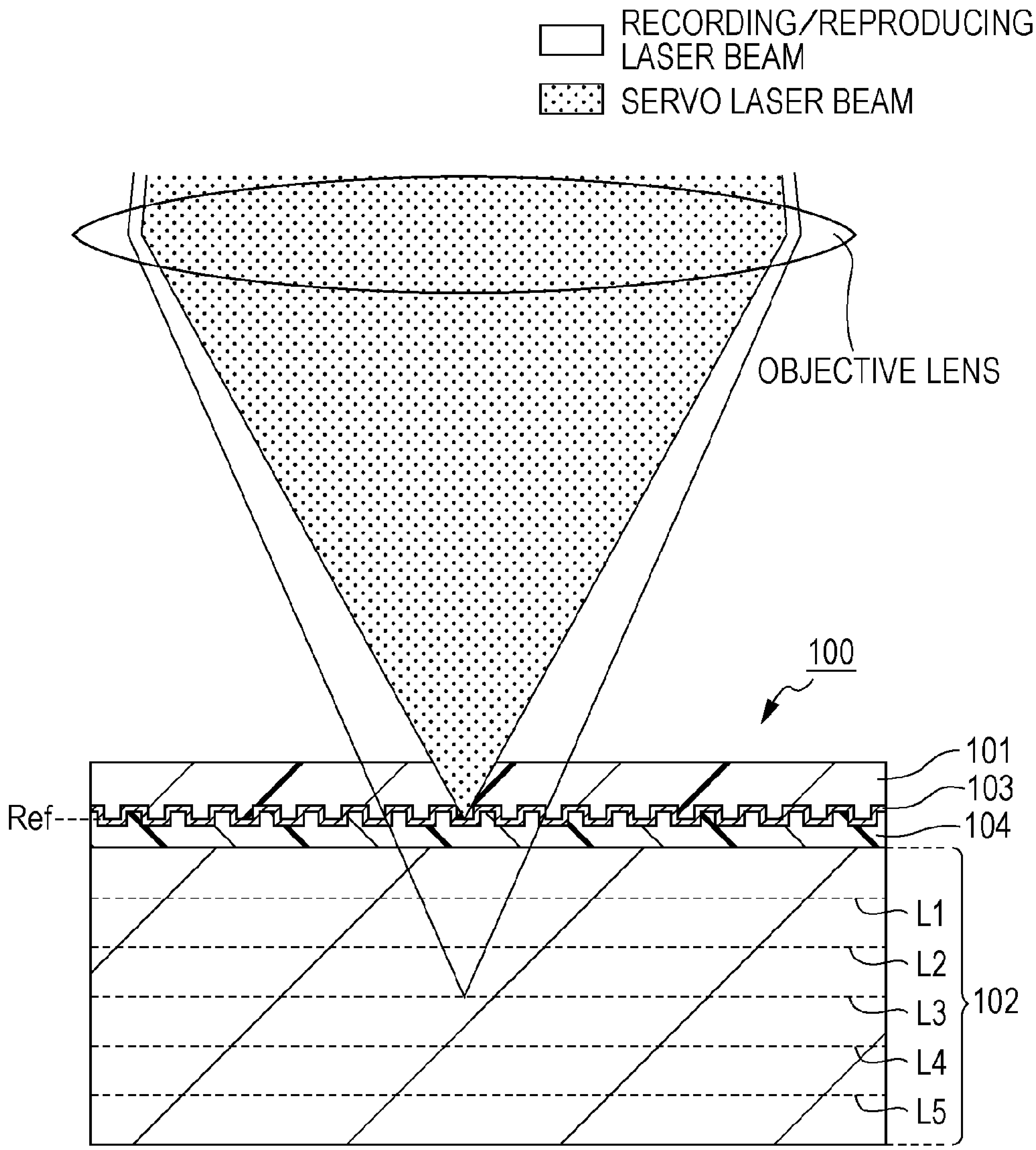
DSV CONTROL IS NOT PERFORMED
DSV CONTROL IS PERFORMED
1e+06
100000
10000
1000
PSD
10^{-4}
10^{-3}
10^{-2}
10^{-1}
NORMALIZED FREQUENCY

FIG. 26



PRIOR ART

FIG. 27



PRIOR ART

ENCODING DEVICE, ENCODING METHOD, RECORDING DEVICE, RECORDING METHOD, OPTICAL RECORDING MEDIUM, DECODING DEVICE AND DECODING METHOD

RELATED APPLICATIONS

The present application claims priority to Japanese Patent Application JP 2010-106319 filed in the Japan Patent Office on May 6, 2010.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an encoding device and method for converting an m-bit data word into an n-bit code word. In addition, the invention relates to a recording device and method for recording a recording code string obtained by encoding and a recording medium. In addition, the invention relates to a decoding device and method for decoding a recording code string.

2. Description of the Related Art

As optical recording media for performing recording/reproduction of a signal by light irradiation, for example, so-called optical discs such as a Compact Disc (CD), Digital Versatile Disc (DVD) or Blu-ray Disc (BD) (registered trademark) have come into wide use.

In the optical discs widely used in the present state, mark edge recording for defining a recording code as Non Return to Zero Inverting (NRZI) and performing recording after conversion into Non Return to Zero (NRZ) code upon recording is performed.

In the optical discs, due to the relationship for obtaining a tracking error signal from a groove, pit, or the like, few low band components of a recording code are necessary. That is, a tracking servo band is lower than a signal band of a recording code. However, if there are many low band components in the recording code, the components of the recording code may be superimposed on the tracking error signal such that the tracking servo characteristics are deteriorated.

Accordingly, in the optical disc of the related art, the low band components of the recording code are suppressed by controlling the absolute value of the Digital Sum Value (DSV) of the recorded NRZ code string to be decreased.

For example, in a CD, an encoding method of using an EFM modulation code, satisfying a limit of a minimum run length d=2 between a 14-bit code word and the next code word, and selecting and inserting predetermined 3 connection bits so as to decrease the absolute value of the DSV of the code string is used.

In a DVD, using a modulation code called EFM Plus, with respect to a certain data word, a code word of a main table and a substitution table which decreases the absolute value of the DSV of the code string is selected and encoded so as to perform DSV control. This modulation code is described, for example, in Kees A. Schouhamer Immink "EFMPlus: THE CODING FORMAT OF THE MULTIMEDIA COMPACT DISC", IEEE Transaction on Consumer Electronics, Vol. 41, Issue 3, August 1995 and International Publication No. 95/22802.

In a BD, a modulation code called 17PP is used, but a DC control bit is periodically defined in a recording data format of the BD. Thus, encoding is performed after the DC control bit of "0" or "1", which decreases the absolute value of the DSV of the code string, is selected.

With respect to an optical disc which is widely used in the present state of the CD, the DVD, the BD and the like, first, as a next-generation optical disc, the present applicant proposes a so-called bulk recording type optical disc (simply referred to as a bulk type) described in Japanese Unexamined Patent Application Publication No. 2008-135144 or Japanese Unexamined Patent Application Publication No. 2008-176902.

Here, bulk recording indicates, for example, a technology of realizing a large amount of recording capacity by irradiating a laser beam to an optical recording medium (bulk type recording medium **100**) having at least a cover layer **101** and a bulk layer (recording layer) **102** while sequentially changing a focal point position so as to perform multi-layer recording in the bulk layer **102**, as shown in FIG. **26**.

In such bulk recording, Japanese Unexamined Patent Application Publication No. 2008-135144 discloses recording technology which is a so-called micro hologram method. In the micro hologram method, a so-called hologram recording material is used as a recording material of the bulk layer **102**. As the hologram recording material, for example, a photopolymerizable photopolymer or the like is widely used.

The micro hologram method is classified broadly into a positive type micro hologram method and a negative type micro hologram method.

The positive type micro hologram method is a method of focusing two opposing light fluxes (light flux A and light flux B) at the same position so as to form a minute interference fringe (hologram) and using the minute interference fringe as a recording mark.

The negative type micro hologram method is a method of erasing an interference fringe formed in advance by laser beam irradiation and using the erased portion as a recording mark, in opposition to the positive type micro hologram method. In the negative type micro hologram method, a process for forming an interference fringe in the bulk layer is performed in advance, as an initialization process.

The present applicant proposes, for example, a recording method of forming a void (blank or hole) disclosed in Japanese Unexamined Patent Application Publication No. 2008-176902 as a recording mark, as a bulk recording method different from the micro hologram method.

The void recording method is, for example, a method of irradiating a laser beam to the bulk layer **102** formed of a recording material such as a photopolymerizable photopolymer with relatively high power so as to record a blank in the bulk layer **102**. As described in Japanese Unexamined Patent Application Publication No. 2008-176902, the formed blank portion has a refractive index different from that of the other portion of the bulk layer **102** and thus the light reflection ratio of the boundary portion thereof is increased. Accordingly, the blank portion functions as a recording mark and thus information recording by formation of a blank mark is realized.

In such a void recording method, since the hologram is not formed, recording is completed by light irradiation from one side. That is, as in the positive type micro hologram method, it is not necessary to focus two light fluxes at the same position so as to form the recording mark.

In addition, in comparison with the negative type micro hologram method, it is an advantage that the initialization process is not performed.

In Japanese Unexamined Patent Application Publication No. 2008-176902, although an example of irradiating a pre-cure light before recording at the time of performing void recording is described, void recording is possible even when the irradiation of the pre-cure light is omitted.

However, the bulk recording type (also simply referred to as bulk type) optical disc recording medium is proposed as the above various recording methods, but the recording layer (bulk layer) of the bulk type optical disc recording medium does not have an explicit multi-layer structure in the sense that, for example, a plurality of reflection films is formed. That is, in the bulk layer **102**, a reflection film and a guide groove are not provided in every recording layer included in a general multi-layer disc.

Accordingly, in the structure of the bulk type recording medium **100** as it is shown in FIG. **26**, focus servo and tracking servo may not be performed during recording in which the mark is not formed.

Accordingly, practically, in the bulk type recording medium **100**, a reflection surface (reference surface) is provided which becomes a reference having guide grooves shown in FIG. **27**.

More specifically, the guide grooves (position guide elements) such as pits or grooves are formed in a lower surface side of the cover layer **101** in a spiral shape or a concentric shape and a selective reflection film **103** is formed on the guide grooves. The bulk layer **102** is laminated on the lower layer side of the cover layer **101**, on which the selective reflection film **103** is formed, with an adhesive material interposed therebetween as an intermediate layer **104** in the figure, such as a UV curing resin.

Here, through the formation of the guide grooves such as pits or grooves, for example, recording of absolute position information (address information) such as radius position information or rotation angle information is performed. In the following description, a surface (in this case, a surface on which the selective reflection film **103** is formed) in which such guide grooves are formed and the absolute position information is recorded is referred to as a "reference surface Ref".

After such a medium structure is formed, as shown in the figure, not only a laser beam (hereinafter, referred to as a recording/reproduction laser beam or simply a recording/reproduction light) for recording (or reproducing) a mark but also a servo laser beam (simply referred to as a servo light) as a laser beam for position control is irradiated to the bulk type recording medium **100** through a common objective lens.

At this time, if the servo laser beam reaches the bulk layer **102**, the mark recording in the bulk layer **102** may be adversely affected. Accordingly, in the bulk recording method of the related art, the laser beam having a wavelength range different from that of the recording/reproduction laser beam is used as the servo laser beam, and the selective reflection film **103** having wavelength selectivity, which reflects the servo laser beam and transmits the recording/reproduction laser beam, is provided as the reflection film formed on the reference surface Ref.

On the above assumption, the operation at the time of mark recording for the bulk type recording medium **100** will be described. First, when multi-layer recording is performed with respect to the bulk layer **102** in which the guide grooves and the reflection film are not formed, the layer position where the mark is recorded in a depth direction in the bulk layer **102** is set in advance. In the figure, the case where a total of 5 information recording layer positions L including a first information recording layer position L**1** to a fifth information recording layer position L**5** are set as a layer position (mark forming layer position; also referred to as an information recording layer position) where the mark is formed in the bulk layer **102** is shown. As shown, in the information recording layer position L, the first information recording layer position L**1** is provided at an uppermost side and, next, the information recording positions L**2**, L**3**, L**4** and L**5** are sequentially provided toward a lower layer side.

During recording in which the mark is not yet formed, a focus servo control and a tracking servo control are not performed based on the reflected light of the recording/reproduction laser beam with respect to the layer positions in the bulk layer **102** as a target. Accordingly, the focus servo control and the tracking servo control of the objective lens during recording are performed so as to enable the spot position of the servo laser beam to follow the guide grooves on the reference surface Ref based on the reflected light of the servo laser beam.

It is necessary for the recording/reproduction laser beam to reach the bulk layer **102** formed on the lower layer side of the selective reflection film **103** than the reference surface Ref and to select the focusing position in the bulk layer **102**, for mark recording. To this end, in an optical system in this case, a focus mechanism (expander) for the recording/reproduction light is provided, which independently adjusts a focusing position of the recording/reproduction laser beam, separately from the focus mechanism of the objective lens.

That is, the focusing position of the recording/reproduction laser beam is adjusted independently of the servo laser beam, by changing collimation of the recording/reproduction laser beam incident to the objective lens by the provided expander.

The position of the recording/reproduction laser beam in the tracking direction is automatically controlled to a position just below the guide grooves in the reference surface Ref by the tracking servo of the objective lens using the above servo laser beam.

In addition, when reproduction is performed with respect to the bulk type recording medium **100** in which mark recording is already performed, it is not necessary to control the position of the objective lens based on the reflected light of the servo laser beam, as during recording. That is, during reproduction, focus servo control and tracking servo control of the objective lens based on the reflected light of the recording/reproduction laser beam are performed, using a mark row formed at the information recording layer position L (also referred to as an information recording layer L or a mark formation layer L, during reproduction) to be reproduced as a target.

SUMMARY OF THE INVENTION

As described above, in the optical disc system of the related art, the low band of the recording code is suppressed by controlling the absolute value of the Digital Sum Value (DSV) of a recorded NRZ code string so as to be decreased.

However, in the encoding method using the connection bits as in the CD, since 8 bits are converted into 17 bits, an encoding rate is 8/17, which is lower than an encoding rate 1/2=0.5 of the code of d=2 which is generally recognized as 27RLL or the like. Thus, recording capacity efficiency is decreased.

In the DVD, the code word of the main table and the substitution table which decreases the absolute value of the DSV of the code string is selected and encoded with respect to any given data word so as to perform DSV control. Since the encoding rate of EFM Plus is 8/16=0.5, it is improved as compared to EFM. However, since a code transition state is also added to a sliding block code, error propagation may occur in a decoding process when channel bit detection error occurs.

In the BD, the modulation code called 17PP is used, but a DC control bit is periodically defined in a recording data format of the BD. Thus, encoding is performed after the DC control bit of "0" or "1" is selected at one timing at 45 bits of data so as to decrease the absolute value of the DSV of the code string. The encoding rate of 17PP is 2/3 which is equal to that of general code of d=1, but DC control bits are necessary. To this end, since conversion efficiency including a format becomes (45/46)×(2/3), recording capacity efficiency is also decreased.

The invention is made to solve encoding rate deterioration and error propagation upon decoding and, more particularly, it is desirable to provide an encoding method suitable for a bulk recording method (multi-layer recording) for performing mark edge recording.

According to an embodiment of the present invention, there is provided an encoding device for converting m-bit data words into n-bit (both n and m are integers and $2^n \geq 2^m \times 2$) code words, including a first encoding table in which 2^m code words selected from the 2^n n-bit code words correspond to 2^m m-bit data words, a second encoding table in which 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words, and an encoding unit which selects and outputs a code word, in which an absolute value of a code string DSV is smaller, from code words corresponding to the input m-bit data words in the first encoding table and code words corresponding to the input m-bit data words in the second encoding table.

Code words in which the number of symbols "1" is an odd number in the second encoding table may correspond to data words to which code words in which the number of symbols "1" is an even number correspond to the first encoding table, and code words in which the number of symbols "1" is an even number in the second encoding table may correspond to data words to which code words in which the number of symbols "1" is an odd number correspond to the first encoding table.

In any one set of code words in which the number of symbols "1" is an even number in the first encoding table and a set of code words in which the number of symbols "1" is an odd number in the second encoding table, the code words may be aligned in ascending order of code word DSV when the code words are NRZ-converted so as to correspond to the data words, and, in the other of the sets, the code words may be aligned in descending order of code word DSV when the code words are NRZ-converted so as to correspond to the data words, and, in any one set of code words in which the number of symbols "1" is an odd number in the first encoding table and a set of code words in which the number of symbols "1" is an even number in the second encoding table, the code words may be aligned in ascending order of code word DSV when the code words are NRZ-converted so as to correspond to the data words, and, in the other of the sets, the code words may be aligned in descending order of code word DSV when the code words are NRZ-converted so as to correspond to the data words.

The encoding unit may select the code words such that a run length limitation of a shortest 0 consecutive length d ($d \neq 0$) and a longest 0 consecutive length k ($k > d$) of a code string obtained from the encoding result is satisfied.

The encoding unit may respectively convert the input m-bit data word into a first code word and a second code word by the first encoding table and the second encoding table, and determine whether both the first code word and the second code word satisfy the run length limitation when the first code word and the second code word are connected to a code word output at one preceding time and select and output a code word in which the absolute value of the code string DSV of the first code word and the second code word is smaller if both the first code word and the second code word satisfy the run length limitation.

For example, d=2, k=10, encoding rate is m/n=1/2, m=8 and n=16.

According to another embodiment of the present invention, there is provided an encoding method for converting m-bit data words into n-bit (both n and m are integers and $2^n \geq 2^m \times 2$) code words, including selecting and outputting a code word, in which an absolute value of a code string DSV is smaller, from code words corresponding to the input m-bit data words in a first encoding table in which 2^m code words selected from the 2^n n-bit code words correspond to 2^m m-bit data words and code words corresponding to the input m-bit data words in a second encoding table in which 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words.

According to another embodiment of the present invention, there is provided a recording device including a recording unit which performs recording with respect to an optical recording medium based on the code words output from an encoding unit, in addition to a first encoding table, a second encoding table and the encoding unit.

The recording unit may record NRZ data obtained by performing inverting to a symbol "1" and non-inverting to a symbol "0" with respect to an encoded string of code words encoded by the encoding unit in the optical recording medium.

The optical recording medium may be a bulk type optical recording medium having a bulk layer for selectively performing mark recording at a plurality of positions in a depth direction, and the recording unit may record marks by a blank in the bulk layer.

According to another embodiment of the present invention, there is provided a recording method including performing recording with respect to an optical recording medium based on code words output by the encoding procedure, in addition to the encoding procedure of the encoding method.

According to another embodiment of the invention, there is provided a bulk type optical recording medium having a bulk layer for selectively performing mark recording at a plurality of positions in a depth direction, wherein a mark row is recorded in the bulk layer based on code words obtained by performing an encoding process of selecting and outputting a code word, in which an absolute value of a code string DSV is smaller, from code words corresponding to the m-bit data words in a first encoding table in which 2^m code words selected from the 2^n n-bit code words correspond to 2^m m-bit data words and code words corresponding to the m-bit data words in a second encoding table in which 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words.

The mark row recorded in the bulk layer may be a mark row based on NRZ data obtained by performing inverting to a symbol "1" and non-inverting to a symbol "0" with respect to an encoded string of encoded code words.

The mark row recorded in the bulk layer may be a mark row by marks formed by blanks.

According to another embodiment of the present invention, there is provided a decoding device including a decoding unit which includes first and second decoding tables in which code words and data words have the same correspondence as first and second encoding tables and searches both a first decoding table and a second decoding table for m-bit data words corresponding to input n-bit code words and outputs the m-bit data words.

According to another embodiment of the invention, there is provided a decoding method including searching both a first decoding table and a second decoding table for m-bit data words corresponding to input n-bit code words and outputting the m-bit data words.

In the encoding of the invention, a first encoding table in which 2^m code words selected from the 2^n n-bit code words correspond to 2^m m-bit data words and a second encoding table in which 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words are prepared. The encoding process of selecting and outputting a code word, in which an absolute value of a code string DSV is smaller, from code words corresponding to the input m-bit data words in the first encoding table and code words corresponding to the input m-bit data words in the second encoding table is performed.

If a run length limitation is considered, there is a limitation as to which of the first and second encoding tables the code word is extracted from in data words at any given time. However, if the run length limitation is satisfied even when the code word is extracted from any given table, the code words may be arbitrarily selected. In this case, by selecting the code word in which the code string DSV is close to zero, it is possible to perform DSV control.

In order to suitably perform DSV control, in the invention, the first and second encoding tables have the following characteristics.

The code words of the first and second encoding tables are all independent and the code words do not overlap with each other.

In the first and second encoding tables, the number of symbols “1” is an odd number in one of the code words corresponding to the same data word and the number of symbols “1” is an even number in the other of the code words corresponding to the same data word. Therefore, the two code words corresponding to the same data word become the code words of a direction in which the code string DSV is increased and a direction in which the code string DSV is decreased.

The code words corresponding to the data words may be aligned in descending order of code word DSV in one of the first and second encoding tables, and may be aligned in ascending order of code word DSV in the other of the first and second encoding tables. That is, the two code words corresponding to the same data word are closer to the absolute value of DSV in the first and second encoding tables.

According to the invention, it is possible to perform encoding such that the code string DSV is as close to zero as possible. In the case of employing a bulk recording method for performing multi-layer recording by mark edge recording in a bulk layer, it is possible to perform suitable encoding. As a result, it is possible to realize reproduction stabilization of the bulk type recording medium.

In the invention, since the code words stored in the first encoding table and the second encoding table do not overlap with each other, so-called error propagation in which a decoding error of one preceding time causes error in a next decoding result does not occur.

According to the decoding device (and decoding method) of the invention, it is possible to suitably and easily decode the code string obtained by encoding of the invention and, as a result, to realize decoding without error propagation.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing the configuration of a recording/reproduction device according to an embodiment of the invention;

FIG. **2** is a cross-sectional structural diagram of an optical recording medium of an embodiment of the invention;

FIGS. **3**A and **3**B are views illustrating NRZ, NRZI and DSV according to an embodiment of the invention;

FIG. **4** is a view illustrating classification of code words according to an embodiment of the invention;

FIG. **5** is a view illustrating the structure of an encoding table according to an embodiment of the invention;

FIG. **6** is a view illustrating an example of an S**1** encoding table according to an embodiment of the invention;

FIG. **7** is a view illustrating an example of an S**1** encoding table according to an embodiment of the invention;

FIG. **8** is a view illustrating an example of an S**1** encoding table according to an embodiment of the invention;

FIG. **9** is a view illustrating an example of an S**1** encoding table according to an embodiment of the invention;

FIG. **10** is a view illustrating an example of an S**2** encoding table according to an embodiment of the invention;

FIG. **11** is a view illustrating an example of an S**2** encoding table according to an embodiment of the invention;

FIG. **12** is a view illustrating an example of an S**2** encoding table according to an embodiment of the invention;

FIG. **13** is a view illustrating an example of an S**2** encoding table according to an embodiment of the invention;

FIG. **14** is a view illustrating ascending and descending order of DSV values of an encoding table according to an embodiment of the invention;

FIGS. **15**A and **15**B are views illustrating the structure of an encoding table according to an embodiment of the invention;

FIG. **16** is a view illustrating an encoding process according to a comparative example;

FIG. **17** is a flowchart of an encoding process according to a comparative example;

FIG. **18** is a view illustrating an encoding example according to a comparative example;

FIG. **19** is a view illustrating an encoding process according to an embodiment of the invention;

FIG. **20** is a flowchart illustrating an encoding process according to an embodiment of the invention;

FIG. **21** is a view illustrating an encoding example according to an embodiment of the invention;

FIG. **22** is a view illustrating a decoding process according to an embodiment of the invention;

FIG. **23** is a flowchart of a decoding process according to an embodiment of the invention;

FIG. **24** is a view illustrating a code string DSV when encoding according to an embodiment of the invention is performed;

FIG. **25** is a view illustrating low band suppression when encoding according to an embodiment of the invention is performed;

FIG. **26** is a view illustrating a bulk recording method; and

FIG. **27** is a view showing the cross-sectional structure of a bulk type recording medium and servo control upon recording/reproduction.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, embodiments of the invention will be described in the following order.

1. Configuration of Recording/reproduction Device and Optical Recording Medium

2. Encoding Table

3. Comparative Example (the case where DSV control is not performed)

4. Encoding Process of Embodiment
5. Decoding Process
6. Effect of Embodiment and Modified Example

1. Configuration of Recording/Reproduction Device and Optical Recording Medium

FIG. **1** is a diagram showing the internal configuration of a recording/reproduction device according to an embodiment of the invention.

First, a bulk type recording medium **1** of the figure is a bulk type optical recording medium having a recording layer as a bulk layer, similar to the description of FIG. **27**.

The bulk type recording medium **1** is a disc-shaped optical recording medium, in which mark recording (information recording) is performed by irradiating a laser beam to the rotated and driven bulk type recording medium **1**. Reproduction of the recording information is also performed by irradiating a laser beam to the rotated and driven bulk type recording medium **1**.

The optical recording medium is the generic term for a recording medium for recording/reproduction information by light irradiation.

FIG. **2** is a cross-sectional structural diagram of the bulk type recording medium **1**.

As shown in FIG. **2**, in the bulk type recording medium **1**, a cover layer **2**, a selective reflection film **3**, an intermediate layer **4**, and a bulk layer **5** are sequentially formed from an upper layer side.

In the present specification, the "upper layer side" indicates an upper layer side when a light incident surface side of a device for irradiating a laser beam in order to perform recording or reproduction is an upper surface.

Although the term "depth direction" is used in the present specification, the term "depth direction" indicates a direction matched to a vertical direction according to the definition of the "upper layer side" (that is, a direction parallel to the incident direction of the laser beam from the device side: focus direction).

In the bulk type recording medium **1**, the cover layer **2** is formed of, for example, resin such as polycarbonate or acrylic and, as shown, a lower surface side thereof has an uneven cross-sectional shape as shown in the figure by forming guide grooves as position guide elements for guiding a recording/reproduction position. The position guide elements are formed in a spiral shape or a concentric shape.

As the guide grooves, consecutive grooves or pit rows are formed. For example, if the guide grooves are formed of pit rows, position information (absolute position information: rotation angle information, radius position information, or the like as information indicating a rotation angle position on a disc) is recorded by a combination of the lengths of pits and lands. Alternatively, if the guide grooves are formed of grooves, the grooves are periodically formed in a zigzag (wobble) manner so as to record position information by periodic information of the zigzag.

The cover layer **2** is generated by injection molding or the like using a stamper in which, for example, such guide grooves are formed (uneven shape).

The selective reflection film **3** is formed on a lower surface side of the cover layer **2**, in which the guide grooves are formed.

As described above, in a bulk recording method, a light (servo laser beam) for obtaining a tracking or focus error signal based on the above guide grooves is irradiated separately from a light (recording/reproduction laser beam) for

performing mark recording/reproduction with respect to the bulk layer **5** as a recording layer.

At this time, if the servo laser beam reaches the bulk layer **5**, the mark recording in the bulk layer **5** may be adversely affected. Accordingly, a reflection film having selectivity for reflecting the servo laser beam and transmitting the recording/reproduction laser beam is necessary.

In the bulk recording method of the related art, laser beams having different wavelength ranges are used in the recording/reproduction laser beam and the servo laser beam and, in correspondence therewith, a selective reflection film having wavelength selectivity, which reflects a light having the same wavelength range as the servo laser beam and transmits a light having the other wavelength range, is used as the selective reflection film **3**.

In the case of this example, the recording/reproduction laser beam has a wavelength of about 405 nm and the servo laser beam has a wavelength of about 640 nm.

The bulk layer **5** as the recording layer is laminated (adhered) on the lower layer side of the selective reflection film **3** with the intermediate layer **4** interposed therebetween, which is formed of, for example, an adhesive material such as UV curing resin.

As the material (recording material) of the bulk layer **5**, an optimal material is appropriately employed, for example, according to the employed bulk recording method such as the above-described positive type micro hologram method, the negative type micro hologram method or the void recording method.

In addition, the mark recording method of the optical recording medium of the invention is not specially limited and a certain method may be employed in the range of the bulk recording method. In the following description, for example, a void (blank) recording method is employed.

In the bulk type recording medium **1** having the above configuration, the selective reflection film **3** in which the position guide elements are formed as the above-described guide grooves becomes a reflection surface which is a reference for performing the position control of the recording/reproduction laser beam based on the servo laser beam, as described below. In this sense, in the embodiment, the surface on which the selective reflection film **3** is formed is hereinafter referred to as a reference surface Ref.

As described in FIG. **27**, in the bulk type optical recording medium, in order to perform multi-layer recording within the bulk layer, each layer position (information recording layer position L) in which information recording will be performed is set in advance. Although an illustrated description is omitted, even in the bulk type recording medium **1** according to the present embodiment, a necessary number of information recording layer positions L is set.

Now, detailed examples of each layer position will be described. The information recording layer position L located at an uppermost portion is set to a position of about 100 μm from a front surface (uppermost surface) of the bulk type recording medium **1**. An information recording layer position L located at a lowermost portion is set to a position of about 300 μm from the front surface.

Information recording layer positions L between the information recording layer position L of the uppermost portion and the information recording layer position L of the lowermost portion are provided such that an interval between the adjacent information recording layer positions L is 10 μm on an average in consideration of interlayer crosstalk.

In addition, the position of the reference surface Ref is a position of about 50 μm from the front surface and an interval from the reference surface Ref to the information recording layer position L of the uppermost portion becomes about 50 μm.

Description returns to FIG. **1**.

In the recording/reproduction device according to the embodiment, an optical pickup **14** for irradiating a recording/reproduction laser beam to the bulk type recording medium **1** is provided.

In the optical pickup **14**, a recording/reproduction laser beam source and a servo laser beam source for respectively emitting the recording/reproduction laser beam and the servo laser beam described in FIG. **27** are provided. An objective lens for focusing and irradiating the recording/reproduction laser beam and the servo laser beam to the bulk type recording medium **1** or a biaxial actuator for holding the objective lens which may be driven in a tracking direction and a focus direction are also provided. A spectroscopic element (for example, dichroic prism or the like) for synthesizing the recording/reproduction laser beam and the servo laser beam emitted from the respective light sources on the same axis and guiding the beams to the objective lens and separating the reflected light of the recording/reproduction laser beam and the reflected light of the servo laser beam incident through the objective lens from the bulk type recording medium **1** into different optical paths or a recording/reproduction light receiving unit for receiving the reflected light of the recording/reproduction laser beam and a servo light receiving unit for receiving the reflected light of the servo laser beam are also included.

As described in FIG. **27**, a recording/reproduction focus mechanism (expander) for changing collimation of the recording/reproduction laser beam incident to the objective lens is also provided. By providing the recording/reproduction focus mechanism, during recording, it is possible to selectively record marks with respect to the necessary information recording layer position L set in the bulk layer **5**, under the condition that focus servo of the objective lens is performed with respect to the reference surface Ref by the servo laser beam.

In practice, in the recording/reproduction device, although a servo circuit for performing control of the irradiation position of the laser beam based on the reflected light of the servo laser beam during recording described in FIG. **27** or irradiation position control of the laser beam based on the reflected light of the recording/reproduction laser beam during reproduction, a slide mechanism of the optical pickup **14**, and a spindle motor for rotating and driving the bulk type recording medium **1** are also provided. However, since these components are not directly related to an encoding process or a decoding process of the embodiment, they are not shown and described herein.

In the recording/reproduction device, as components for generating a code string (recording code string) to be recorded in the bulk layer **5**, an encoding unit **10**, an S**1** encoding table **11** and an S**2** encoding table **12** are provided.

The encoding unit **10** sequentially converts m-bit data word of input recording data into n-bit code word using the S**1** encoding table **11** and the S**2** encoding table **12** so as to perform encoding of the recording data.

In addition, the encoding process of the embodiment using the S**1** encoding table **11** and the S**2** encoding table **12** by the encoding unit **10** will be described again later.

The S**1** encoding table **11** and the S**2** encoding table **12** are stored in an internal or external memory device of the encoding unit **10**.

The recording code string obtained by the encoding process using the encoding unit **10** is supplied to a recording control unit **13**.

The recording control unit **13** light emission-drives the above-described recording/reproduction laser beam source in the optical pickup **14** based on the recording code string and executes mark recording in the bulk layer **5**.

In this case, the recording control unit **13** performs the Non Return to Zero (NRZ) modulation process performed by an optical disc system of, for example, a Digital Versatile Disc (DVD) or a Blu-ray Disc (BD: registered trademark) of the related art with respect to the recording code string and light emission-drives the recording/reproduction laser beam so as to perform so-called mark edge recording.

In the present example, the recording control unit **13** light emission-drives the recording/reproduction laser beam source such that a mark is recorded in correspondence with an H level ("1") of a pulse when the recording code string is subjected to NRZ modulation and a space is formed in correspondence with an L level ("0").

The reflected light from the mark recorded in the bulk type recording medium **1** is detected by the recording/reproduction light receiving unit in the above-described optical pickup **14** so as to obtain a reproduction signal.

The reproduction signal of the mark row obtained in this way is amplified by an amplifier **15** and gain thereof is adjusted by an Auto Gain Control (AGC) circuit **16**.

The reproduction signal passing through the AGC circuit **16** is supplied to a Phase Locked Loop (PLL) circuit **17** and an A/D converter **18** as shown in the figure.

The PLL circuit **17** generates a clock CLK by a PLL process based on the reproduction signal. The clock CLK is supplied to a clock of each necessary unit such as the A/D converter **18**.

The A/D converter **18** digitally samples the reproduction signal. The reproduction signal sampled by the A/D converter **18** is supplied to an equalizer (EQ) **19**.

The equalizer **19** and a Viterbi decoder **20** are provided in order to binarize the reproduction signal by a so-called Partial Response Maximum Likelihood (PRML) decoding method.

The equalizer **19** performs a PR equalization process with respect to the reproduction signal sampled by the A/D converter **18** according a predetermined PR class (for example, 1:2:2:1, 1:2:2:2:1, or the like) and outputs the processed signal to the Viterbi decoder **20**.

The Viterbi decoder **20** performs a Viterbi decoding process with respect to the PR-equalized reproduction signal so as to obtain a binarized reproduction signal.

The binarized reproduction signal (corresponding to the above-described recording code string) obtained by the Viterbi decoder **20** is supplied to a decoding unit **21**.

The decoding unit **21** sequentially converts the n-bit data word of the code string as the binarized reproduction signal into m-bit data word using an S**1** decoding table **22** and an S**2** decoding table **23** so as to obtain a reproduction data row.

In addition, the details of the decoding process using the S**1** decoding table **22** and the S**2** decoding table **23** by the decoding unit **21** will be described again later.

The S**1** decoding table **22** and the S**2** decoding table **23** are stored in an internal or external memory device of the decoding unit **21**.

Here, the configuration of the recording/reproduction device shown in FIG. **1** is not limited thereto.

For example, although the case of performing the binarization process of the reproduction signal by the PRML decoding process is described, the binarization method of the reproduction signal is not limited thereto.

The PLL process of the generation of the clock CLK may be configured to be realized by, for example, a digital PLL process such as an Interpolated Timing Recovery (ITR) method.

The recording/reproduction device according to the embodiment of the invention has an advantage in the encoding process of generating the recording code string in consideration of the recording and reproducing characteristic of the optical recording medium and in the decoding process of decoding the code string. In particular, encoding in which DSV control is appropriately executed is performed.

This point will be described.

As optical reading characteristics of the optical recording medium such as an optical disc, Modulation Transfer Function (MTF) is well known.

This function has low-pass characteristics having a cutoff in which a spatial frequency of 2·NA/λ or more may not be read, when an aperture ratio of an optical pickup is NA and a laser wavelength is λ. Therefore, upon high-density recording, wave equalization of high band emphasis is performed in order to approach an eye pattern of a desired waveform of a partial response or the like.

However, it is difficult to perform equalization even when any high band emphasis is performed for cutoff.

In an NRZI modulation code having a limitation of a minimum run length d≠0, since at least d "0"s are inserted between 1 indicating inversion and the next 1, it is possible to prevent a channel bit row after NRZ conversion from being inverted every channel clock by a recording control circuit. As a result, by shifting the frequency spectrum of the recording channel bit row to a low band, it is possible to easily pass through the MTF. This is the reason that a modulation code having a limitation d is generally used in the optical disc (the case of mark edge recording).

When timing clock synchronization is performed using the PLL circuit, it is necessary to obtain a phase error signal from a reproduction waveform and a clock edge.

At this time, if the reproduction signal is not inverted at a predetermined time interval, an opportunity to perform PLL synchronization is reduced and clock jitter is increased. Accordingly, it is necessary to provide a limitation k (>d) of a maximum run length.

In addition, as described in the related art, from an object that tracking servo is not influenced, a DC control function for suppressing a low band component to the modulation code having limitations d and k.

For DC control, DSV control of the code string is performed, but, before the description thereof, DSV will be defined herein.

As shown in FIG. **3**B, an NRZI code string is converted into an NRZ code string converted into a symbol of 1 and is recorded in an optical recording medium.

Here, in NRZ, High (+1) is denoted by 1 and Low (−1) is denoted by 0.

1 of NRZ is +1, 0 of NRZ is −1, and integration thereof is also referred to as "code string DSV".

As shown in FIG. **3**A, there is a 16-bit or NRZI code word. NRZ before the code word ends with 0, and the integration value of DSV when the code word is converted into an NRZ code word is referred to as "code word DSV".

In the figure, the code word DSV of the code word A becomes 6. 1 in the case where the NRZI code word A is NRZ converted is +1, 0 is −1, the integration value within the code word is (11-5).

Similarly, the code word DSV of the code word B becomes 4.

For example, the code word DSV=6 of the code word A indicates that, when the code word A is NRZ-converted and a preceding NRZ symbol ends with 0, DSV is increased by 6.

Similarly, when the code word B is NRZ-converted and a preceding NRZ symbol ends with 0, DSV is increased by 4.

However, if the code words A and B are consecutive in the NRZ code string of FIG. **3**B, since NRZ=1 at a time k=0, the code string DSV becomes −6 by subtracting (inverting a signal and adding) the code word DSV at k=1. At k=2, since NRZ=0 at k=1, the code string DSV becomes −2 by adding 4 to −6 at k=1.

That is, if the value of preceding NRZ after each code is 0, the code word DSV is added to the preceding code string DSV, and, if the value of the preceding NRZ is 1, the code word DSV is subtracted so as to obtain the code string DSV. Hereinafter, a process of generating a code string of d=2 and k=10 while m=8 bits of data words is converted into n=16 bits of code words will be described.

First, a code word set for generating an encoding table for generating a code string of the invention will be defined, an encoding process of the case where DSV control is not performed will be described, and then an encoding process for performing DSV control will be described.

2. Encoding Table

Now, the S**1** encoding table **11** and the S**2** encoding table **12** used in encoding of the embodiment will be described.

First, as described above, in the present embodiment, it is assumed that, as encoding of converting m bits (m is an integer of 1 or more) of data word into n bits (n is an integer of 1 or more) code word, encoding of m=8 and n=16 is performed. An encoding rate is m/n=1/2.

In the embodiment, a code string obtained by the encoding result is encoded such that the run length limitation of the shortest 0 consecutive length d (d≠0) and the longest 0 consecutive length k (k>d) is satisfied. More specifically, in this example, the run length limitation satisfies d=2 and k=10. In other words, the consecutive length of symbol "0" is limited to 2 or more and 10 or less.

On the assumption of such a condition, in this example, the code word stored in the S**1** encoding table **11** and the 16-bit code words stored in the S**2** encoding table **12** are selected as follows. The following matters are schematically shown in FIG. **4**.

First, there are 302 16-bit binary code words, in which a symbol starts at "1" or "01", a run length limitation of d=2 and k=10 is satisfied between symbols "1" midway, and a symbol consecutively ends with "1" or 9 or less "0"s. A set of code words is referred to as S**1**.

In addition, there are 256 16-bit binary code words, in which a symbol starts at 2 or more and 9 or less "0"s, a run length limitation of d=2 and k=10 is satisfied between symbols "1" midway, and a symbol consecutively ends with "1" or 9 or less "0"s. A set of code words is referred to as S**2**.

Since m=8, a code word set S**2** is assigned to 2^8=256 kinds of data in one-to-one correspondence.

Among the code words of S**1**, there are 154 code words in which the number of symbols of "1" is an even number and a set thereof is referred to as S**1**-even.

Among the code words of S**1**, there are 148 code words in which the number of symbols of "1" is an odd number and a set thereof is referred to as S**1**-odd.

Among the code words of S**2**, there are 126 code words in which the number of symbols of "1" is an even number and a set thereof is referred to as S**2**-even.

Among the code words of S**2**, there are 130 code words in which the number of symbols of “1” is an odd number and a set thereof is referred to as S**2**-odd.

As described below, in this example, upon an encoding process of converting 8-bit data words into 16-bit code words, DSV control is performed by selecting a candidate of a code word of S**1** or S**2**.

It is advantageous that the code word in which the number of symbols of “1” of one candidate is an odd number is assigned to the code word in which the number of symbols of “1” of one candidate is an even number, because the increase/decrease of DSV is reversed.

Therefore, S**2**-odd corresponds to S**1**-even and S**2**-even corresponds to S**1**-odd as pairs.

Since S**2** has no scope for selection from the 256 code words, 130 code words are selected from 154 code words of S**1**-even and form with pairs of 130 code words of S**2**-odd. That is, among 256 data words, as 130 code words corresponding to 130 data words, 130 code words included in S**1**-even are selected from S**1** and 130 code words included in S**2**-odd are selected from S**2**.

With respect to the code words corresponding to the remaining 126 data words, 126 code words are selected from 143 code words of S**1**-odd, 126 code words are assigned in S**2**-even, and they form pairs.

In addition, correspondence is performed such that a value obtained by adding a value of the code word DSV of S**1**-even and a value of the code word DSV of S**2**-odd is as close to 0 as possible. Similarly, correspondence is performed such that a value obtained by adding a value of the code word DSV of S**1**-odd and a value of the code word DSV of S**2**-even is as close to 0 as possible.

A set of code words in which a symbol ends with consecutive 2 or more and 9 or less “0”s in S**1** is S**11** and a set of code words which a symbol ends with “1” or “10” is S**12**.

A set of code words in which a symbol ends with consecutive 2 or more and 9 or less “0”s in S**2** is S**21** and a set of code words which a symbol ends with “1” or “10” is S**22**.

FIG. **5** shows connection between the image of a set of codes of S**1** and S**2** and data word. There is no overlapping code word in S**1** or S**2** and there is no overlapping code word in S**1** and S**2**. To this end, it is possible to simply perform decoding upon the below-described decoding.

The S**1** encoding table **11** and the S**2** encoding table **12** of this example are obtained by assigning code words corresponding to data words based on the above point.

The S**1** encoding table **11** stores a set of (256) code words of S**1** as code words to be associated with 256 data words.

Similarly, the S**2** encoding table **12** stores a set of (256) code words of S**2** as code words to be associated with 256 data words.

Examples of the S**1** encoding table **11** are shown in FIGS. **6**, **7**, **8** and **9**. Examples of the S**2** encoding table **12** are shown in FIGS. **10**, **11**, **12** and **13**.

In FIGS. **6** to **9** and FIGS. **10** to **13**, data words of 0 to 255 are shown on the left end. “Data” is a HEX display of data words.

With respect to each data word, 16-bit code words are shown as “Code”.

The state of each code word indicates a transition state.

Among the code words of S**1** of FIGS. **6** to **9**, in S**11**, “1” is recorded in a next transition state. As shown in FIG. **5**, if a code of a certain S**1** is connected after this code word, it is indicated that d=2 and k=10 of the code string are typically held.

In S**12**, “2” is recorded in a next transition state. As shown in FIG. **5**, if a code of a certain S**2** is connected after this code word, it is indicated that d=2 and k=10 of the code string are typically held.

Among the code words of S**2** of FIGS. **10** to **13**, in S**21**, “1” is recorded in a next transition state. As shown in FIG. **5**, if a code of a certain S**1** is connected after this code word, it is indicated that d=2 and k=10 of the code string are typically held.

In S**22**, “2” is recorded in a next transition state. As shown in FIG. **5**, if a code of a certain S**2** is connected after this code word, it is indicated that d=2 and k=10 of the code string are typically held.

In FIGS. **6** to **9** and FIGS. **10** to **13**, a code word DSV is shown as “DSV” with respect to each code word.

Further, with respect to each code word, “O/E” indicates that the number of “1”s within the code word is an even number or an odd number. “O/E” of “0” denotes a code word in which the number of “1”s is an even number and “O/E” of “1”s is a code word in which the number of “1”s is an odd number.

That is, in the S**1** encoding table **11** of FIGS. **6** to **9**, the above-described 130 code words of S**1**-even have “O/E” of In this example, code words of S**1**-even may be assigned as 130 code words corresponding to data values “0” to “129”.

In contrast, in the S**2** encoding table **12** of FIGS. **10** to **13**, 130 code words of S**2**-odd have “O/E” of “1” and may be assigned as code words corresponding to data values “0” to “129”.

In addition, in the S**1** encoding table **11** of FIGS. **6** to **9**, 126 code words of S**1**-odd have “O/E” of “1” and may be assigned as code words corresponding to data values “130” to “255”.

In contrast, in the S**2** encoding table **12** of FIGS. **10** to **13**, 126 code words of S**2**-even have “O/E” of “0” and may be assigned as code words corresponding to data values “130” to “255”.

The code word DSV of the code words of the S**1** encoding table **11** and the S**2** encoding table **12** is as follows.

In the data word “0” to “129” of the S**1** encoding table **11**, the code words having code word DSV of “−4” to “6” may be assigned in descending order of the code word DSV.

In the data words “130” to “255” of the S**1** encoding table **11**, the code words having code word DSV of “−6” to “8” may be assigned in descending order of the code word DSV.

In the data words “0” to “129” of the S**2** encoding table **12**, the code words having code word DSV of “6” to “−8” may be assigned in ascending order of the code word DSV.

In the data words “130” to “255” of the S**2** encoding table **12**, the code word DSV having code words of “6” to “−10” may be assigned in ascending order of the code word DSV.

The ascending and descending order state of the code word DSV is shown in FIG. **14**.

That is, the code words are selected such that the data words “0” to “255” are aligned in descending order of values of the code word DSV in the S**1** encoding table **11** and are aligned in ascending order of values of the code word DSV in the S**2** encoding table **12**.

FIG. **15**A schematically shows the structures of the S**1** encoding table **11** and the S**2** encoding table **12**.

In the S**1** encoding table **11**, the code words of S**1**-even in which the number of symbols “1” is an even number may be assigned to data words “0” to “129” of the first half. In addition, the order is a descending order of values of the code word DSV.

The code words of S**1**-odd in which the number of symbols “1” is an odd number may be assigned to data words “130” to

"255" of a second half of the S1 encoding table 11. In addition, the order is a descending order of values of the code word DSV.

In the S2 encoding table 12, the code words of S1-odd in which the number of symbols "1" is an odd number may be assigned to data words "0" to "129" of a first half. In addition, the order is an ascending order of values of the code word DSV.

The code words of S1-even in which the number of symbols "1" is an even number may be assigned to data words "130" to "255" of a second half of the S2 encoding table 12. In addition, the order is an ascending order of values of the code word DSV.

In summary, the S1 encoding table 11 and the S2 encoding table 12 have the following characteristics.

First, the code words of the S1 encoding table 11 and the S2 encoding table 12 are all independent and the code words do not overlap with each other. These are tables for converting m-bit data words into n-bit code words, in which n and m are both integers, $2^n \geq 2^m \times 2$, a condition for selecting all independent code words is satisfied in the two tables, and all independent code words are selected.

Next, in the S1 encoding table 11 and the S2 encoding table 12, the number of symbols "1" is an odd number in one of the code words corresponding to the same data word and the number of symbols "1" is an even number in the other of the code words corresponding to the same data word.

Therefore, the two code words of the S1 encoding table 11 and the S2 encoding table 12 corresponding to the same data word become the code words of a direction in which the code string DSV is increased and a direction in which the code string DSV is decreased.

Further, the code words corresponding to the data words may be aligned in a descending order of code word DSV in one of the S1 encoding table 11 and the S2 encoding table, and may be aligned in an ascending order of code word DSV in the other of the S1 encoding table 11 and the S2 encoding table. That is, the two code words corresponding to the same data word are closer to the absolute value of DSV in the S1 encoding table 11 and the S2 encoding table 12.

In addition, in this example, although the S1 encoding table 11 and the S2 encoding table 12 have the above-described characteristics, the relationship between the odd number and the even number and the code word DSV relationship may be reversed.

At least, the number of symbols "1" is an even number in one of the two code words corresponding to one data word and is an odd number in the other of the two code words. The alignment order of values of the code word DSV may be the ascending order in the S1 encoding table 11 and may be the descending order in the S2 encoding table 12.

A description will be given for confirmation. Although "State", "DSV" and "O/E" are shown along with the data words and the code words in FIGS. 6 to 13, the values of "O/E" do not have to be stored in the S1 encoding table 11 and the S2 encoding table 12. "O/E" may be determined from the code words itself by the number of "1".

As described with reference to FIG. 5, "State" is stored in the tables, because the table, from which a code word is next extracted, indicates any one of the S1 encoding table 11 and the S2 encoding table 12, in order to satisfy the run length limitation. However, this is obtained by sequentially confirming the alignment of the symbols "0" and "1" of the code words and does not have to be stored in the tables in advance.

Since the values of the code word DSV of the code words are used when obtaining the code string DSV of the connection state in the below-described connection confirmation (process ST 14 of FIG. 19 and step F205 of FIG. 20), the values of "DSV" are stored in the tables. Since the code word DSV may be easily calculated from the code words, it may be obtained upon processing and does not have to be stored in the tables in advance.

The encoding process of the present embodiment using the S1 encoding table 11 and the S2 encoding table 12 is schematically as follows.

Fundamentally, the run length limitation may be satisfied by determining from which of the S1 encoding table 11 and the S2 encoding table 12 the code word corresponding to the input data word is extracted.

For example, FIG. 15B shows a state in which a data word D0 at a time t0 is encoded into a code word S1-C0 using the S1 encoding table 11. When "State" encounters "2" with respect to the code word S1-C0, a data word D1 of a next time t1 is encoded into S2-C1 using the S2 encoding table 12.

If "State" is "1" with respect to the code word S2-C1, the run length limitation is satisfied when the data word D2 of a next time t2 is encoded into S1-C2 using the S1 encoding table 11. However, even when the data word D2 is encoded into S2-C2 using the S2 encoding table 12, the run length limitation is satisfied. In this case, any one of the S1 encoding table 11 and the S2 encoding table 12 may be used. In the present embodiment, in this case, in consideration of the code string DSV, any one of the S1 encoding table 11 and the S2 encoding table 12 is selected. If the absolute value of the code string DSV is decreased when the data word is encoded into S2-C2 using the S2 encoding table 12, the code word S2-C2 is selected.

3. Comparative Example

Case where DSV Control is not Performed

Now, before the description of the encoding process of the embodiment, as a comparative example, encoding satisfying the run length limitation of d=2 and k=10 using the S1 encoding table 11 and the S2 encoding table 12 will be described. In this method, DSV control is not performed.

FIG. 16 shows an internal signal process of the encoding unit 10 when DSV control is not performed, in a block form.

The recording data row is converted into a bus by 8 bits (process ST1).

A data word D_t of a time t (integer) when a data row is increased by 8 bits is delivered to the S1 encoding table 11 and the S2 encoding table 12 through the bus.

By a circuit such as a wired OR (Wired-OR), a table is looked up and a combination {C_t(S1), state (S1)} and {C_t (S2), state (S2)} of the 16-bit code words corresponding to the data words D_t of the S1 encoding table 11 and the S2 encoding table 12 and the states are output (processes ST2 and ST3).

The next state block is a memory in which one selected from the state (S1) or the state (S2) one preceding time is stored. If the next state signal which is this output is 1, C_t (S1) is selected and output as C_t and state (S1) is output to the next state block.

In contrast, if the next state signal is 2, C_t (S2) is selected and output as C_t and state (S2) is output to the next state block (processes ST4, ST5, ST6 and ST7).

FIG. 17 is a flowchart illustrating the encoding process of the encoding unit 10 as the comparative example.

First, in step F101, the encoding unit 10 encodes the input data word using the S1 encoding table 11 and outputs the obtained code word.

That is, in this case, a first input data word is encoded by the S1 encoding table 11.

Alternatively, the first input data word may be encoded by the S2 encoding table 12.

In the subsequent step F102, the encoding unit 10 determines whether or not encoding has to be finished (for example, whether or not all data to be recorded is encoded, or the like). If a negative result that encoding does not have to be finished yet is obtained, the process proceeds to step F103.

If a positive result that encoding has to be finished is obtained, the encoding process is finished as shown in the figure.

In step F103, the encoding unit 10 acquires the State value of the output code word and, in the subsequent step F104, a determination as to whether the State value 1 or 2 is made.

In step F104, if it is determined that the State value is 1, the process returns to step F101 of encoding the input data word using the S1 encoding table 11 and outputting the code word.

In contrast, if it is determined that the State value is 2, the process proceeds to step F105 of encoding the input data word using the S2 encoding table 12 and outputting the code word obtained as the result. After the code word is output in step F105, the process returns to step F102 as shown in the figure.

If only the satisfaction of the run length limitations is considered, the next input data word is simply encoded using any one of the S1 encoding table 11 and the S2 encoding table 12 according to the State value of the output code word.

For example, if a data word row is input at a next state=1 of a time t=0, encoding is performed as shown in FIG. 18.

In FIG. 18, t is a time, D_t is a data word of the time t, and C_t is a code word of the time t. The data word of the time t=1 is denoted by "D1" and the code word thereof is denoted by "C1". In addition, the next state becomes the State value of the code word one preceding time. A preceding end NRZ indicates whether the NRZ code of the code word of one preceding time is "0" or "1". Further, it indicates the code word DSV and the code string DSV of each time.

In the example shown in this figure, the input data word at the time 1 is "0x05" at t=0, is "0xfc" at t=1, is "0xf7" at t=2, "0x84" at t=3, is "0xfa" at t=4, and "0x07" at t=5.

For example, first, at the time t=0, the input data word D0="0x05" is encoded using the S1 encoding table 11 and the code word C0 of "1001000000100100" is output. Since the State value of the code word at the time t=0 is "1", the data word D1="0xfc" is encoded using the S1 encoding table 11 and the code word C1 of "1000000000100010" is output.

Further, since the State value of the code word at the time t=1 is "2", the data word D2="0xf7" at the sequential time t=2 is encoded using the S2 encoding table 12 and the code word C2 of "0000000010001000" is output.

As the result of sequentially performing encoding using the S1 encoding table 11 or the S2 encoding table 12 according to the State value, the code string DSV of the times t=0 to 5 sequentially become −4, 4, 12, 18, 8 and 4.

4. Encoding Process of Embodiment

Contrary to the encoding process of the comparative example, in the encoding process of the present embodiment, DSV control is performed. Hereinafter, the present embodiment will be described.

FIG. 19 shows an internal signal process of the encoding unit 10 of the embodiment, in which the DSV control is performed, in a block form.

The recording data row is converted into a bus by 8 bits (process ST11). A data word D_t of a time t (integer) when the data row is increased by 8 bits is delivered to the S1 encoding table 11 and the S2 encoding table 12 through the bus.

By a circuit such as a wired OR (Wired-OR), a table is looked up and 16-bit code words C_t (S1) and C_t (S2) corresponding to the data words D_k of the S1 encoding table 11 and the S2 encoding table 12 are output (processes ST12 and ST13).

With respect to the code words C_t (S1) and C_t (S2), it is checked whether or not the connection relationship with the code word C_t−1 output at one preceding time satisfies d=2 and k=10 and selects a code word (process ST14). Then the selected code word is output (process ST15). The selected code word is held as the code word C_t−1 at one preceding time at the process of a next time (process ST16).

More specifically, the following operations are performed.

First, with respect to the code word C_t−1 of one preceding time, when the code words C_t (S1) and C_t (S2) are respectively connected, it is checked whether or not the connection relationship (run length limitation) is satisfied.

Here, in the case where only the code word C_t (S1) satisfies the connection relationship and C_k (S2) does not satisfy the connection relation is referred to as a condition 1.

In the case where the code word C_t (S1) does not satisfy the connection relationship and only C_t (S2) satisfies the connection relation is referred to as a condition 2.

In addition, in the case where both C_t (S1) and C_t (S2) satisfy the connection relationship is referred to as a condition 3.

In the condition 1, C_t (S1) is output as the code word C_t at this time.

In the condition 2, C_t (S2) is output as the code word C_t at this time.

In the condition 3, when each of the code words of C_t (S1) and C_t (S2) is connected to the code string up until that point, one side in which the value of the code string DSV is closer to 0 is selected and is output as the code word C_t at this time.

In addition, when the code word C_t−1 ends with a symbol "1" or "10", the condition of d=2 and k=10 is satisfied even when being connected to any code word of the S2 encoding table 12.

In addition, when the code word C_k−1 ends with 2 or more and 9 or less "0"s, the condition of d=2 and k=10 is satisfied even when being connected to any code word of the S1 encoding table 11.

That is, this means that any one of the condition 1, the condition 2 and the condition 3 is typically satisfied. Thus, when the encoded string is generated by the above process, the connection relationship is typically held. FIG. 20 is a flowchart illustrating the encoding process of the encoding unit 10 of the embodiment.

First, in step F201, the encoding unit 10 decodes the input data word D_t using the S1 encoding table 11 and outputs the obtained code word C_t. In addition, t denotes a time.

Even in this case, the first input data word may be encoded using the S2 encoding table instead of the S1 encoding table 11.

In step F202, the encoding unit 10 determines whether or not encoding has to be finished.

In step F202, if a negative result that encoding does not have to be finished yet is obtained, the encoding unit 10 proceeds to step F203 of holding the output code word C_t as C_t−1.

In step F202, if a positive result that encoding has to be finished is obtained, the encoding unit 10 finishes the series of encoding processes shown in this figure.

The encoding unit 10 encodes a next input data word D_t using both the S1 encoding table 11 and the S2 encoding table 12 in step F204, after holding the code word C_t as the code word C_t−1 in step F**203**. Thus, as shown in FIG. **19**, the code words C_t (S**1**) and C_t (S**2**) are obtained.

In the subsequent step F**205**, the encoding unit **10** performs a connection checking process of the code words C_t (S**1**) and C_t (S**2**) for the code word C_t−1. That is, it is checked whether or not the run length limitation is satisfied even when any one of the code words C_t (S**1**) and C_2 (S**2**) is connected.

In practice, since it may be checked that one side satisfies the run length limitation from the State value of the code word of one preceding time, it is checked whether or not the run length limitation is satisfied with respect to the code word of the other side which is not expressed by the State value.

In next step F**206**, the encoding unit **10** branches the process depending on whether or not the connection of both the code words C_t (S**1**) and C_t (S**2**) is OK, as the checking result.

If any one of C_t (S**1**) and C_t (S**2**) does not satisfy the run length limitation, the encoding unit **10** proceeds to step F**207** of determining whether or not only the code word C_t (S**1**) is OK, that is, whether or not only the code string, to which the code word C_t (S**1**) is connected, satisfies the run length limitation.

If only the code word C_t (S**1**) is OK, that is, in the above-described condition 1, the encoding unit **10** proceeds to step F**208** of outputting the code word C_t (S**1**) as the code word C_t and then returns to step F**202**.

If only the code word C_t (S**2**) is OK, that is, in the above-described condition 2, the encoding unit **10** proceeds to step F**209** of outputting the code word C_t (S**2**) as the code word C_t and then returns to step F**202**.

In contrast, if the connection of both the code words C_t (S**1**) and C_t (S**2**) is OK, that is, in the condition 3, the encoding unit **10** proceeds to steps F**206** to F**210**.

The encoding unit **10** connects each of the code words C_t (S**1**) and C_t (S**2**) to the code string up until that point and calculates the value of the code string DSV. A code word in which the code string DSV is closer to **0** (a code word in which the absolute value of the code string DSV is smaller) is selected and is output as the code word C_t at this time. Thereafter, the encoding unit returns to step F**202**.

By such a process, encoding is performed.

For example, if encoding starts at the code of the S**1** encoding table **11** in the case of t=0 and the same data word row as the comparative example in which the DSV control is performed as shown in FIG. **18** is input, encoding is performed as shown in FIG. **21**. In FIG. **21**, in addition to the same items as FIG. **18**, the above-described conditions 1, 2 and 3 are shown as the connection condition.

At the time t=0, it is assumed that Next State=1, preceding end NRZ=0 and code string DSV=0 are set as an initial state.

Since data word D**0**=0x05, the code word C**0** of "1001000000100100" is selected from the S**1** encoding table **11**. In this case, the code word DSV=−4 and the end NRZ=0 are added to the code string DSV without change so as to become −4.

At the time t=1, the data word D**1**=0xfc is input. At this time, there are two candidates of the code word C**1** (S**1**) of the S**1** encoding table **11** and the code word C**1** (S**2**) of the S**2** encoding table **12**.

Here, when the code words C**1** (S**1**) and the C**1** (S**2**) are connected, it is determined whether all the conditions 1, 2 and 3 are satisfied. In this case, since the code word C**0** of one preceding time ends with two "0"s, the code word C**1** (S**1**) starts with "1" (see FIG. **9**), and the code word C**1** (S**2**) starts with 6 "0"s (see FIG. **13**), both the code words satisfy d=2 and k=10. Thus, the condition 3 is satisfied.

In this case, a code word in which the absolute value of the code string DSV is smaller is selected as the control of the code string DSV.

In addition, since the number of symbols "1" of the code words of the code word C**0** of one preceding time is an even number, the preceding end NRZ is not inverted and is "0" and the code word DSV is added when the code string DSV is obtained.

Since the code word DSV of the code word C**1** (S**1**) is 8 and the code word DSV of the code word C**1** (S**2**) is −10, when they are added to the code string DSV=−4 at the time t=0 and when they are connected to the code word C**1** (S**1**), the code string DSV becomes +4. When the code word C**1** (S**2**) is connected, the code string DSV becomes −14. As a result, since the code word C**1** (S**1**) is closer to 0, the former C**1** (S**1**) is selected as the code word C**1** at this time.

At the time t=2, the data word D**2**=0xf7 is input. At this time, there are two candidates of the code word C**2** (S**1**) of the S**1** encoding table **11** and the code word C**2** (S**2**) of the S**2** encoding table **12**. Since the code word C**1** of one preceding time ends with one "0", C**2** (S**1**) starts with one "0" (see FIG. **9**), and C**2** (S**2**) starts with eight "0"s (see FIG. **13**), both the data words satisfy d=2 and k=10, and, even in this case, the condition 3 is satisfied. Thus, control of the code string DSV is considered.

Since the number of symbols "1" of the code words of the code word C**1** of one preceding time is an odd number, the preceding end NRZ is inverted and is "1" and the code word DSV is subtracted when the code string DSV is obtained.

Since the code word DSV of the code word C**2** (S**1**) is 6 and the code word DSV of the code word C**2** (S**2**) is −8, when they are subtracted from the code string DSV=4 at the time t=1 and the code string DSV, to which the code word C**2** (S**1**) is connected, becomes −2. In addition, the code string DSV, to which C**2** (S**2**) is connected, becomes +12. Since the code word C**2** (S**1**) is closer to 0, the former C**2** (S**1**) is selected as the code word C**2** at this time.

At the time t=3, the data word D**3**=0x84 is input. At this time, there are two candidates of the code word C**3** (S**1**) of the S**1** encoding table **11** and the code word C**3** (S**2**) of the S**2** encoding table **12**. Since the code word C**2** of one preceding time ends with "1", C**3** (S**1**) starts with one "0" (see FIG. **8**), and C**3** (S**2**) starts with four "0"s (see FIG. **12**), only C**3** (S**2**) satisfies d=2 and k=10 and the condition 2 is satisfied. Thus, C**3** (S**2**) is selected as the code word C**3** at this time.

In this case, since the number of symbols "1" of the code words of the code word C**2** of one preceding time is an odd number, the preceding end NRZ is inverted and is "0" and the code word DSV is added when the code string DSV is obtained. Since the code word DSV of the code word C**3** (S**2**) is **6**, if it is added to the code string DSV=−2 of the time t=2, the code string DSV of the time t=3 becomes +4.

At the time t=4, the data word D**4**=0xfa is input. At this time, there are two candidates of the code word C**4** (S**1**) of the S**1** encoding table **11** and the code word C**4** (S**2**) of the S**2** encoding table **12**. Since the code word C**3** of one preceding time ends with "1", C**4** (S**1**) starts with "1" (see FIG. **9**), and C**4** (S**2**) starts with four "0"s (see FIG. **13**), only C**4** (S**2**) satisfies d=2 and k=10 and the condition 2 is satisfied. Thus, C**4** (S**2**) is selected as the code word C**4** at this time.

In this case, since the number of symbols "1" of the code words of the code word C**3** of one preceding time is an even number, the preceding end NRZ is "0" and the code word DSV is added when the code string DSV is obtained. Since the code word DSV of the code word C**4** (S**2**) is −10, if it is added to the code string DSV=4 of the time t=3, the code string DSV of the time t=4 becomes −6.

At the time t=5, the data word D5=0x07 is input. At this time, there are two candidates of the code word C5 (S1) of the S1 encoding table 11 and the code word C5 (S2) of the S2 encoding table 12. Since the code word C4 of one preceding time ends with eight "0"s, C5 (S1) starts with "1" (see FIG. 6), and C5 (S2) starts with two "0"s (see FIG. 10), both the data words satisfy d=2 and k=10 and the condition 3 is satisfied. Thus, control of the code string DSV is considered.

Since the number of symbols "1" of the code words of the code word C4 of one preceding time is an even number, the preceding end NRZ is "0" and the code word DSV is added when the code string DSV is obtained.

Since the code word DSV of the code word C5 (S1) is −4 and the code word DSV of the code word C5 (S2) is +6, when they are added to the code string DSV=−6 at the time t=4 and the code string DSV, to which the code word C5 (S1) is connected, becomes −10. In addition, the code string DSV, to which C5 (S2) is connected, becomes 0. Since the code word C5 (S2) is closer to +0, the former C5 (S2) is selected as the code word C2 at this time.

For example, as described above, as compared to the case where DSV control is not performed, it may be seen that the code word in which the code string DSV is closer to 0 is selected.

5. Decoding Process

Next, a method of decoding the code string generated by encoding of the above-described embodiment to the data row will be described.

First, according to the definition of the above-described S1 code word set and S2 code word set, in the present embodiment, the same code word is not overlappingly stored in the S1 encoding table 11 and the S2 encoding table 12.

That is, the code words in the S1 encoding table 11 or the S2 encoding table 12 are all independent and the elements of the code words of both the S1 encoding table 11 and the S2 encoding table 12 are all independent. That is, the product set of S1 and S2 does not exist.

This is a large difference that, for example, as in the code of EFM-Plus employed in a DVD system, the same code word exists in the same state and are assigned to the data words according to a next state such that the number of elements (the number of code words) of the code word set is increased.

In the present embodiment, the non-overlapping of the same code word means that the data word is uniquely obtained in two tables of an S1 decoding table 22 and an S2 decoding table 23 respectively corresponding to the S1 encoding table and the S2 encoding table 12, upon decoding.

More specifically, in this case, decoding is performed as follows.

That is, the decoding unit 21 shown in FIG. 1 searches the S1 decoding table 22 and the S2 decoding table 23 and specifies m bits of data words corresponding to the recording code string received from the Viterbi decoder 20 every n bits of code words. Then, the specified data words are sequentially output as reproduction data.

FIG. 22 shows the data process of the decoding unit 21 in a block form.

A reproduction code string is obtained by the Viterbi decoder 20 and is converted into a 16-bit bus (process ST21). The code word C_t of the time t (integer) when the code (channel bit) is increased by 16 bits is delivered to the S1 decoding table 22 and the S2 decoding table 23 through the bus (processes ST22 and ST23).

The S1 decoding table 22 and the S2 decoding table 23 reversely reads the combination of the code words and the data words of the S1 encoding table 11 and the S2 encoding table 12 shown in FIGS. 6 to 13 without completely recognizing a next state so as to obtain the data words. As the simplest method, the S1 decoding table 22 and the S2 decoding table 23 may store only the correspondence between the data words and the code words of the S1 encoding table 11 and the S2 encoding table 12.

By a circuit such as a wired OR, a table is looked up and the data words are obtained. The decoding unit 21 refers to the S1 decoding table 22 and the S2 decoding table 23 reads the data word D_t with respect to the code word C_t (process ST24).

Upon encoding, the code words are extracted from any one of the S1 encoding table 11 and the S2 encoding table 12 from the data word D_t and the code words do not overlap. Accordingly, upon decoding, the code word C_t is searched for from the S1 decoding table 22 and the S2 decoding table 23 and the data word D_t corresponding thereto is read. FIG. 23 is a flowchart illustrating the process of the decoding unit 21.

The decoding unit 21 repeats the processes of step F302 and F303 whenever the reproduction code word is input, until it is determined that the decoding is finished in step F301.

In step F302, the S1 decoding table 22 and the S2 decoding table 23 are referred to with respect to the input reproduction code word. In step F303, the data word D_t obtained from the tables is output.

As described above, the S1 encoding table 11 and the S2 encoding table 12 have independent code words. Accordingly, it is possible to obtain unique data words from the S1 decoding table 22 and the S2 decoding table 23 corresponding thereto.

The reproduction data row is obtained by the data word Dk output at each time.

In addition, according to this decoding process, decoding is performed by the completely same circuit, with respect to the code obtained by encoding according to the comparative example, in which DSV control is not performed, and the code obtained by encoding according to the embodiment, in which DSV control is performed.

6. Effect of Embodiment and Modified Example

Up to now, the encoding process and the decoding process of the embodiment have been described.

In the encoding process of the embodiment, in the case where the run length limitation is satisfied, the encoding table used in next encoding is not simply selected according to the State value and DSV control is performed if the run length limitation is satisfied even when any encoding table is selected.

That is, a code word in which the absolute value of the code string DSV is selected in a state in which the code word of each table is connected. Accordingly, it is possible to appropriately perform DSV control.

The comparison between the code string DSV when the DSV control of the embodiment is performed and the code string DSV when the DSV control is not performed is shown in FIG. 24. The code word DSV when the DSV control is not performed largely oscillates. In contrast, when the DSV control of the present embodiment is performed, the code string DSV is typically close to 0. The comparison between power spectrum densities of the frequency by the code string when DSV control is performed and DSV control is not performed is shown in FIG. 25. The low frequency component is suppressed by DSV control.

In the EFM of the related art or the encoding of 17 PP or the like, it is necessary to add 1 bit for DC control in addition to the limitations d and k of the code. Although there is a problem that capacity efficiency is decreased in order to decrease the encoding rate, according to the encoding process of the present embodiment, it is possible to obtain the same encoding rate as the encoding rate necessary for the limitations d and k.

For example, the encoding and decoding tables of EFM-Plus have four code set states and the lookup tables have 351 or more elements. The number of code set states of the invention is 2 and 256 elements are included. Since they are all included in hardware or a software program, it is possible to reduce the scale of the implementation of the hardware or software by the encoding method of the invention.

In the code of EFM-Plus, overlapping code words exist in the same state, and thus the number of elements of the code word set is increased by assigning the code words to the data words according to a next state. Accordingly, upon decoding, decoding has to be performed according to a previous encoding state. If an error has occurred in the previous decoding, error propagation in which the next decoding is erroneously performed because of the error may occur.

However, in the present embodiment, the code words of the S**1** encoding table **11** or the S**2** encoding table **12** are all independent and the elements of the code words of the S**1** encoding table **11** and the S**2** encoding table **12** are all independent. That is, the product set of the S**1** encoding table **11** and the S**2** encoding table **12** does not exist. Code words correspond one-to-one to data words in the S**1** encoding table **11** and the S**2** encoding table **12**.

To this end, upon decoding using the S**1** decoding table **22** and the S**2** decoding table **23** including the same correspondence structure between the code words and the data words as the S**1** encoding table **11** and the S**2** encoding table **12**, decoding may be performed without considering the set to which the code word belongs. That is, it is possible to perform decoding in which error propagation does not occur, because it does not depend on the previous state.

Although the embodiments of the invention are described, the invention is not limited to the above-described examples.

For example, the encoding rate is not limited to 8/16. As understood from the above description, in the encoding of this case, as the code words correspond to the same data words in the S**1** encoding table **11** and the S**2** encoding table **12**, at least they do not overlap. In this sense, as the relationship between m and n, at least $2^n \geq 2^m \times 2$ is satisfied.

In the above description, although the run length limitation is d=2 and k=10, the values of d and k are not limited thereto. Even in the run length limitation other than d=2 and k=10, the invention is suitably applicable.

In the above description, in consideration of the run length limitation, with respect to the input data word, the connection between the code words C_t(S**1**) and C_t(S**2**) encoded using the S**1** encoding table **11** and the S**2** encoding table and the code word C_t-1 of one preceding time is checked. In addition, only when both C_t(S**1**) and C_t(S**2**) satisfy the run length limitation, the code word of a code word in which the code string DSV is closer to zero is selected and output. However, for example, if it is not necessary to provide the run length limitation in order to relatively decrease recording density, for each input of m-bit recording data, sequentially, the code word of a code word, in which the code string DSV is closer to zero, of the code word encoded using the S**1** encoding table **11** and the code word encoded using the S**2** encoding table **12** may be selected and output.

In the above description, although the case of applying the encoding device (encoding method) or the recording device (recording method) of the invention to the recording/reproduction device which performs both mark recording and reproduction of recording mark with respect to the recording layer is described, the invention is suitably applicable to a recording device (recording dedicated device) for performing only mark recording with respect to a recording layer.

In the above description, although the case of applying the decoding device (decoding method) of the invention to the recording/reproduction device for performing both mark recording and reproduction of recording mark is described, the invention is suitably applicable to a reproducing device (reproduction dedicated device) for performing only reproduction of recorded marks.

In the embodiment, as the recording/reproduction device, the S**1** encoding table **11** and the S**2** encoding table **12** are included in the encoding unit **10** and the S**1** decoding table **22** and the S**2** decoding table **23** are included in the decoding unit **21**. However, in this case, the S**1** encoding table **11** and the S**2** encoding table **12** are shared in the decoding unit **21** so as to be used in the decoding process. That is, the S**1** decoding table **22** and the S**2** decoding table **23** may not be provided separately from the S**1** encoding table **11** and the S**2** encoding table **12**, respectively. In other words, the S**1** encoding table **11** and the S**2** encoding table **12** may function as the S**1** decoding table **22** and the S**2** decoding table **23**.

The present application contains subject matter related to that disclosed in Japanese Priority Patent Application JP 2010-106319 filed in the Japan Patent Office on May 6, 2010, the entire contents of which are hereby incorporated by reference.

It should be understood by those skilled in the art that various modifications, combinations, sub-combinations and alterations may occur depending on design requirements and other factors insofar as they are within the scope of the appended claims or the equivalents thereof.

What is claimed is:

1. An encoding device for converting m-bit data words into n-bit (both n and m are integers and $2^n \geq 2^m \times 2$) code words, the encoding device comprising:

a first encoding table in which 2^m code words selected from 2^n n-bit code words correspond to 2^m m-bit data words;

a second encoding table in which 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words; and

an encoding unit configured to select and output a code word, in which an absolute value of a code string Digital Sum Value is smaller, from code words corresponding to input m-bit data words in the first encoding table and code words corresponding to input m-bit data words in the second encoding table.

2. The encoding device according to claim **1**, wherein code words in which a number of symbols "1" is an odd number in the second encoding table correspond to data words to which code words in which a number of symbols "1" is an even number correspond to the first encoding table, and code words in which a number of symbols "1" is an even number in the second encoding table correspond to data words to which code words in which a number of symbols "1" is an odd number correspond to the first encoding table.

3. The encoding device according to claim **2**, wherein:

in any one set of code words in which the number of symbols "1" is an even number in the first encoding table and a set of code words in which the number of symbols "1" is an odd number in the second encoding table, the code words are aligned in ascending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words, and, in the other of the sets, the code words are aligned in descending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words, and

in any one set of code words in which the number of symbols "1" is an odd number in the first encoding table and a set of code words in which the number of symbols "1" is an even number in the second encoding table, the code words are aligned in ascending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words, and, in the other of the sets, the code words are aligned in descending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words.

4. The encoding device according to claim **3**, wherein the encoding unit is configured to select the code words such that a run length limitation of a shortest 0 consecutive length d ($d \neq 0$) and a longest 0 consecutive length k ($k > d$) of a code string obtained from an encoding result is satisfied.

5. The encoding device according to claim **4**, wherein the encoding unit is configured to respectively convert the input m-bit data word into a first code word and a second code word by the first encoding table and the second encoding table, and determine whether both the first code word and the second code word satisfy the run length limitation when the first code word and the second code word are connected to a code word output at one preceding time, and select and output a code word in which the absolute value of the code string Digital Sum Value of the first code word and the second code word is smaller if both the first code word and the second code word satisfy the run length limitation.

6. The encoding device according to claim **5**, wherein d=2, k=10, and encoding rate is m/n=1/2.

7. The encoding device according to claim **6**, wherein m=8 and n=16.

8. An encoding method for converting m-bit data words into n-bit (both n and m are integers and $2^n \geq 2^m \times 2$) code words, the method comprising:

performing encoding by selecting and outputting a code word, in which an absolute value of a code string Digital Sum Value is smaller, from code words corresponding to the input m-bit data words in a first encoding table in which 2^m code words selected from 2^n n-bit code words correspond to 2^m m-bit data words and code words corresponding to input m-bit data words in a second encoding table in which 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words.

9. A recording device for converting m-bit data words into n-bit (both n and m are integers and $2^n \geq 2^m \times 2$) code words and performing recording with respect to an optical recording medium, the receiving device comprising:

a first encoding table in which 2^m code words selected from 2^n n-bit code words correspond to 2^m m-bit data words;

a second encoding table in which 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words;

an encoding unit configured to select and output a code word, in which an absolute value of a code string Digital Sum Value is smaller, from code words corresponding to the input m-bit data words in the first encoding table and code words corresponding to the input m-bit data words in the second encoding table; and

a recording unit configured to perform recording with respect to the optical recording medium based at least in part on the code words output from the encoding unit.

10. The recording device according to claim **9**, wherein the recording unit records NRZ data obtained by performing inverting to a symbol "1" and non-inverting to a symbol "0" with respect to an encoded string of code words encoded by the encoding unit in the optical recording medium.

11. The recording device according to claim **10**, wherein the optical recording medium is a bulk type optical recording medium having a bulk layer for selectively performing mark recording at a plurality of positions in a depth direction, and

the recording unit is configured to record marks by a blank in the bulk layer.

12. A recording method for converting m-bit data words into n-bit (both n and m are integers and $2^n \geq 2^m \times 2$) code words and performing recording with respect to an optical recording medium, the method comprising:

selecting and outputting a code word, in which an absolute value of a code string Digital Sum Value is smaller, from code words corresponding to input m-bit data words in a first encoding table in which 2^m code words selected from 2^n n-bit code words correspond to 2^m m-bit data words and code words corresponding to input m-bit data words in a second encoding table in which 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words; and

performing recording with respect to the optical recording medium based on the code words output by the selecting and outputting.

13. A bulk type optical recording medium having a bulk layer for selectively performing mark recording at a plurality of positions in a depth direction, wherein

a mark row is recorded in the bulk layer based at least in part on code words obtained by performing an encoding process of selecting and outputting a code word, in which an absolute value of a code string Digital Sum Value is smaller, from code words corresponding to the m-bit data words in a first encoding table in which 2^m code words selected from 2^n n-bit code words correspond to 2^m m-bit data words and code words corresponding to the m-bit data words in a second encoding table in which 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words, and both n and m are integers and $2^n \geq 2^m \times 2$.

14. The optical recording medium according to claim **13**, wherein the mark row recorded in the bulk layer is a mark row based at least in part on NRZ data obtained by performing inverting to a symbol "1" and non-inverting to a symbol "0" with respect to an encoded string of encoded code words.

15. The optical recording medium according to claim **14**, wherein the mark row recorded in the bulk layer is a mark row of marks formed by blanks.

16. A decoding device comprising a decoding unit which includes first and second decoding tables in which code words and data words have a same correspondence as first and second encoding tables and which searches both a first decoding table and a second decoding table for m-bit data words corresponding to input n-bit code words and outputs the m-bit data words,

in which the first and second encoding tables are used when converting the m-bit data words into the n-bit (both n and m are integers and $2^n \geq 2^m \times 2$) code words,

in the first encoding table, 2^m code words selected from 2^n n-bit code words correspond to 2^m m-bit data words, in the second encoding table, 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words,

code words in which a number of symbols "1" is an odd number in the second encoding table correspond to data words to which code words in which a number of symbols "1" is an even number correspond to the first encoding table,

code words in which a number of symbols "1" is an even number in the second encoding table correspond to data words to which code words in which a number of symbols "1" is an odd number correspond to the first encoding table,

in any one set of code words in which the number of symbols "1" is an even number in the first encoding table and a set of code words in which the number of symbols "1" is an odd number in the second encoding table, the code words are aligned in ascending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words, and, in the other of the sets, the code words are aligned in descending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words,

in any one set of code words in which the number of symbols "1" is an odd number in the first encoding table and a set of code words in which the number of symbols "1" is an even number in the second encoding table, the code words are aligned in ascending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words, and, in the other of the sets, the code words are aligned in descending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words, and

decoding is performed with respect to a code string obtained by performing an encoding process of selecting and outputting a code word, in which an absolute value of a code string Digital Sum Value is smaller, from code words corresponding to the input m-bit data words in the first encoding table and code words corresponding to the input m-bit data words in the second encoding table.

17. A decoding method comprising the steps of searching both a first decoding table and a second decoding table, in which the code words and the data words having a same correspondence as first and second encoding tables, for m-bit data words corresponding to input n-bit code words and outputting the m-bit data words,

in which the first and second encoding tables are used when converting the m-bit data words into the n-bit (both n and m are integers and $2^n \geq 2^m \times 2$) code words,

in the first encoding table, 2^m code words selected from the 2^n n-bit code words correspond to 2^m m-bit data words,

in the second encoding table, 2^m code words, which do not overlap with the code words in the first encoding table, of the 2^n n-bit code words correspond to 2^m m-bit data words,

code words in which a number of symbols "1" is an odd number in the second encoding table correspond to data words to which code words in which a number of symbols "1" is an even number correspond to the first encoding table,

code words in which a number of symbols "1" is an even number in the second encoding table correspond to data words to which code words in which a number of symbols "1" is an odd number correspond to the first encoding table,

in any one set of code words in which the number of symbols "1" is an even number in the first encoding table and a set of code words in which the number of symbols "1" is an odd number in the second encoding table, the code words are aligned in ascending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words, and, in the other of the sets, the code words are aligned in descending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words,

in any one set of code words in which the number of symbols "1" is an odd number in the first encoding table and a set of code words in which the number of symbols "1" is an even number in the second encoding table, the code words are aligned in ascending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words, and, in the other of the sets, the code words are aligned in descending order of code word Digital Sum Value when the code words are NRZ-converted so as to correspond to the data words,

decoding is performed with respect to a code string obtained by performing an encoding process of selecting and outputting a code word, in which an absolute value of a code string Digital Sum Value is smaller, from code words corresponding to the input m-bit data words in the first encoding table and code words corresponding to the input m-bit data words in the second encoding table.

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